Comparative study of approved IMO technologies for treatment of ballast waters

Master's Thesis

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Abstract

Worldwide fleet has continuously been growing during last years, using ballast water almost all of the vessels and increasing the risk of spread of invasive species into local environments. The risk of invasion has pushed the International Maritime Organization to legislate the control and treatment of ballast water to minimize the risks.

For this reason, the International Convention for the Control and Management of Ships' Ballast Water and Sediments has played an essential role for achieving a proper control of the ballasting and de-ballasting process. After the different regulations included on the Convention (mostly standard D-1 and standard D-2), many Ballast Water Management Systems (BWMS) have been approved. The different treatment systems have clearly reduced ballast water impact but the only way for reducing completely the risk of invasion is to reduce the use of ballast water and to design alternative methods. Therefore, the international organizations should act for accomplish the reduction of ballast water usage in the near future and to motivate maritime industry to invest and to study new free-ballast vessel design.

The methodology used during the paper consists on a deep theorical explanation of the ballast water impact (including Ballast Water Management Convention) and a comparison among four different BWMS. The aim of the comparison is to distinguish which system is best regarding the friendliness to the environment and the efficiency for the vessel. After the comparison, different proposals for improving the ballast water impact will be explained to understand how the risk can be even more reduced.

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1.1 Importance of ballast water

Stability of vessels has become more and more important during years as the maritime industry has seen how the size of vessels have been continuously increasing during last decades. New vessels are able to carry incredible weights that clearly affect to the safety of navigation. For this reason, it is very important while loading/discharging cargo to have a perfect operational plan so as to distribute correctly all the weight that changes on the vessel. Moreover, maritime industry realized that it was not enough with a good distribution of weights and new technologies were used for ensuring the safety of the vessels. One of the systems that are used to have a higher control on stability is the ballast water.

Ballast water is used in vessel's tanks to control her stability, her balance and her trim. It consist on water that is loaded directly from the sea so as to refill the ballast tanks and increase the control on the ship. There are mainly two reasons for using ballast waters(1):

- To control the stability while loading or unloading the cargo of the vessel, depending on the weight distribution.
- To have an extra stability in adverse or foul weather conditions.
- To avoid the stress on the hull.

1.2 Main advantages of ballast water

Some of the advantages of the usage of ballast water systems are the following (2):

- Reduction of stress on the hull, the provision of transverse stability, mostly during navigation.
- Improvement of the propulsion of vessel.
- Increase of manoeuvrability during navigation.
- Compensation for weight changes due to differences on cargo levels and due to fuel consumption mostly during navigation (as the change while berthed is insignificant for the stability).

We can say that nowadays it is essential for vessels to use ballast water for their safety and there is no other method or technology that can substitute completely the performance of the ballast water.

1.3 Main disadvantages and secondary effects of ballast water

Despite we have seen that ballast water is essential for a safe navigation and loading/unloading of vessels, there are very important secondary effects affecting mostly to the environment and the species living on the wasters used for that purpose (2).

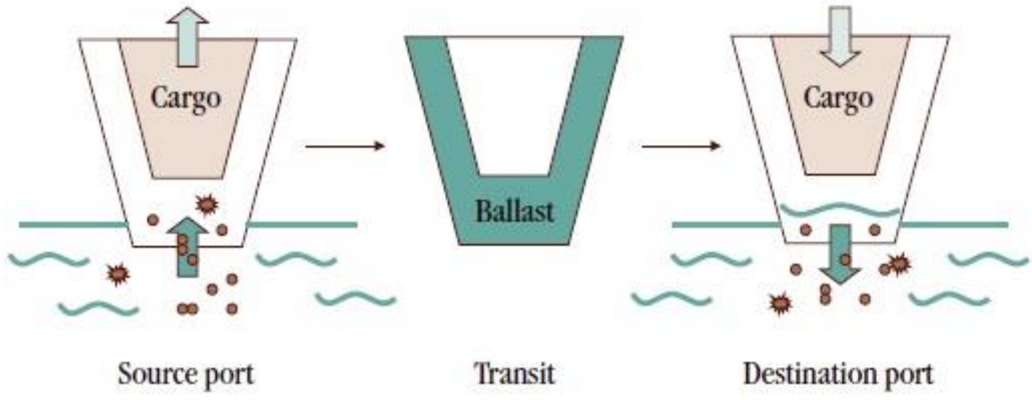


Figure 1. Description of ballasting and de-ballasting process. – Source: http://www.polarcom.gc.ca/eng/content/meridian-newsletter-fallwinter-2011-springsummer-2012-1

Finally, it is essential to remark that the problems caused by the ballast water from ships is continuously increasing as a result of the expansion of the maritime transport, the increase of the size of vessels and the growth of the volumes of trade. Concurrently, it signifies that the bio-invasions will continue growing and will affect more areas that have not been damaged yet.

In Figure 2 it is shown the impact of the ballast water over the world and how important it is for the environment.

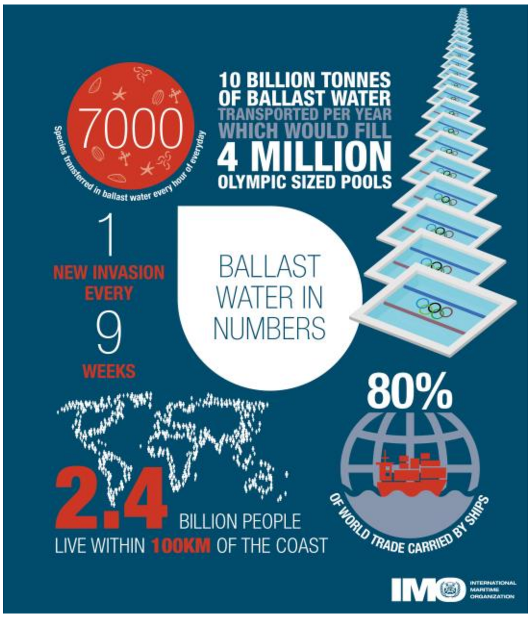


Figure 2. Worldwide impact of BW. – Source: http://www.imo.org/en/MediaCentre/HotTopics/BWM/Pages/default.aspx

1.3.1 Ecological problems

The water that is used for filling ballast tanks is obviously loaded from the sea that the vessel is passing through during that moment. Therefore, while she is loading ballast water, there are entering multitude of species inside the ballast tanks and are being transported to any other sea (depending on the location where the discharge will take place). There can be transported bacterias, microbes, eggs, small invertebrates, cysts and larvae of many different species.

Once these species are discharged in any other environment, if they manage to survive, they can reproduce, and they make increase their population in an area where they have never been established. If the reproduction and the survival of the specie is achieved, they become an invasive species, competing with all native species and in many cases becoming a plague for the new environment.

To have a better idea of the amount of water used by vessels, it is calculated that about 10 billion tonnes of ballast water are carried around the world per year, which signifies a total of 7000 thousand species being transported every hour of every day (2).

First time that is was recognized an invasive specie was in 1903 in the North Sea, when there was a spreading of the Asian phytoplankton algae Odontella. Officially, it was considered in the 1970s the first time scientists studied the ecological problem and it was not until 1980s that Canada and Australia experienced the problem of the invasive species caused by the ballast water from ships. After that, it was the first time the problem was studied by the Marine Environment Protection Committee (MEPC).

1.3.2 Economic problems

There are many economic effects due to the invasive species. Apart from the economic lose for the food industry (reduction in fisheries and aquaculture production), there are economic losses associated to the affection of ships hulls (fouling), buoys or any other structure of harbours. Moreover, indirectly there is an impact on recreational areas and tourism (4).

Finally, it needs to be taken into account the money used for the prevention or control of the invasive species, the eradication of them and the costs of the ballast water systems on board to reduce the impact on the environment (3).

1.3.3 Health problems

The human race is clearly linked to the sea and oceans. A change on the species signifies also a change on the foot change that the human takes place and there can happen a clear affection on the species that human is eating, provoking health problems while eating it.

Furthermore, we need to consider that humans are usually used to the bacterias located in the areas where they are living (4). Due to the ballast water, many bacterias that a human body is not used to can be introduced to it, causing for example problems in the digestive system.

1.4 Growth of the problem worldwide

The merchant fleet has not stopped to grow in the last years. It means that it exists more vessels sailing form one part of the world to another and all the consequences it has both for the environment and for the human health. The growth signifies a higher consume of fuel, more pollution generated by the vessels (Marpol I about sludge and Marpol V about garbage mainly), higher levels of emissions due to the increase of the fleet, more vessels working in terminals nearby the cities (affecting directly to human health)…

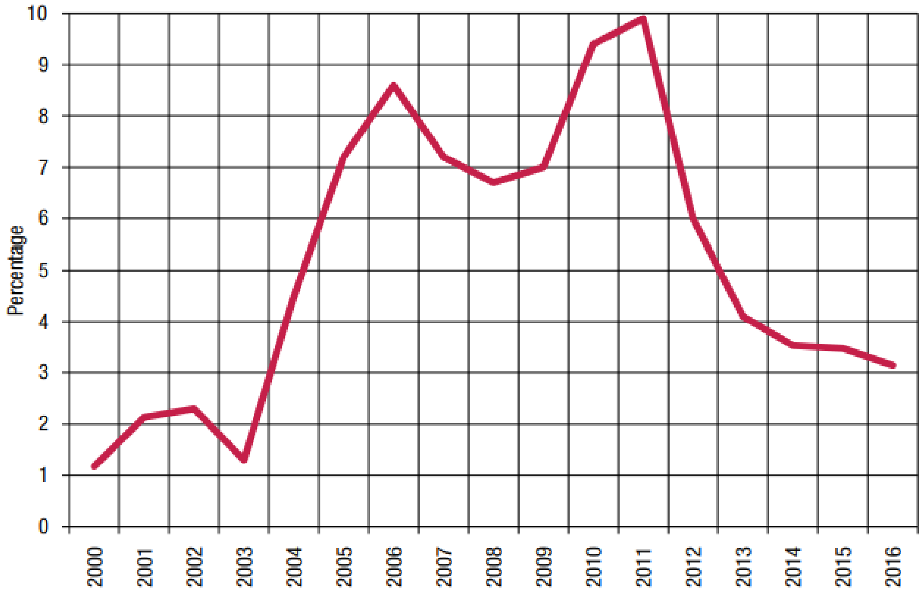


Figure 3. Worldwide fleet growth 2000 - 2016 (in percentage). – Source: http://unctad.org/en/PublicationsLibrary/rmt2017_en.pdf

In Figure 3, we can observe how the fleet has been growing over the years (from 2000 to 2016). Apart from the effects we have already explained, it signifies that the water used for improving the stability has also grown likewise. That grown can clearly show how big the problem is and the need of controlling as much as possible the operations of ballasting and de-ballasting by the different States.

Moreover, it is important to remark that the size of the vessels has also increased significantly for taking profit of the scale economies and they nowadays try to transport as much cargo as possible. This increase of the size does affect completely he ballast water problem, needing higher volumes of water to control the stability of such vessels.

1.5 Example of invasion

There are many cases of invasive species that have reproduced themselves in an environment that were never seen before. Following examples are included in the work to have a clear idea of the affection of those species on local environments and the damage they can produce (5):

- The North American comb jelly (*Mnemiopsis leidy*). This specie appeared the first time in the 1980s in the Black and Azov Sea. It is a specie of jelly that has a quick reproduction, achieving 8000 eggs at a time per adult jelly. Moreover, they can feed themselves as much as they want as they never feel completely full (eating other local species or organisms). The affection of the North American comb jelly in the local fishing industry is calculated on USD250 million a year.

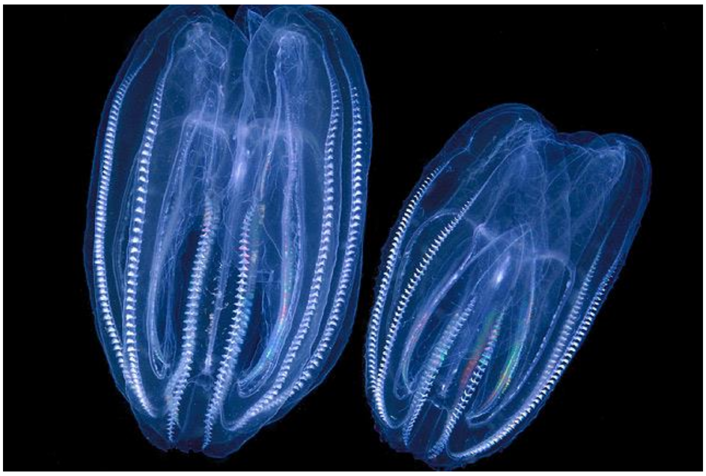


Figure 4. The North American comb jelly *(Mnemiopsis leidy).* – Source: https://www.pinterest.com/pin/153333562285405204/

- The Round Goby (*Neogolus melanosromus*) is a fish which was native from the Black, Asov and Caspian Seas. Due to ballast water, the specie was expanded and introduced into the Baltic Sea and the surroundings of North America. Main problem of this invasive specie is that it compete with other native specie for same food and habitat, being a struggle for survival (6).

Figure 5. The Round Goby *(Neogolus melanosromus).* – Source: http://www.invadingspecies.com/round-goby/

- The zebra mussel *(Dreissena polymorpha)* was native from the Black Sea. The specie was spreaded across western and northern Europe (Ireland and Baltic Sea included) and eastern half of North America. Special damage was suffered in the Great Lakes (around Toronto) around 1988, infesting not only the lakes but also industrial facilities, power generating plants, cooling systems of boat engines, boat hulls… It is said that over USD1 billion was spent to control the invasion.

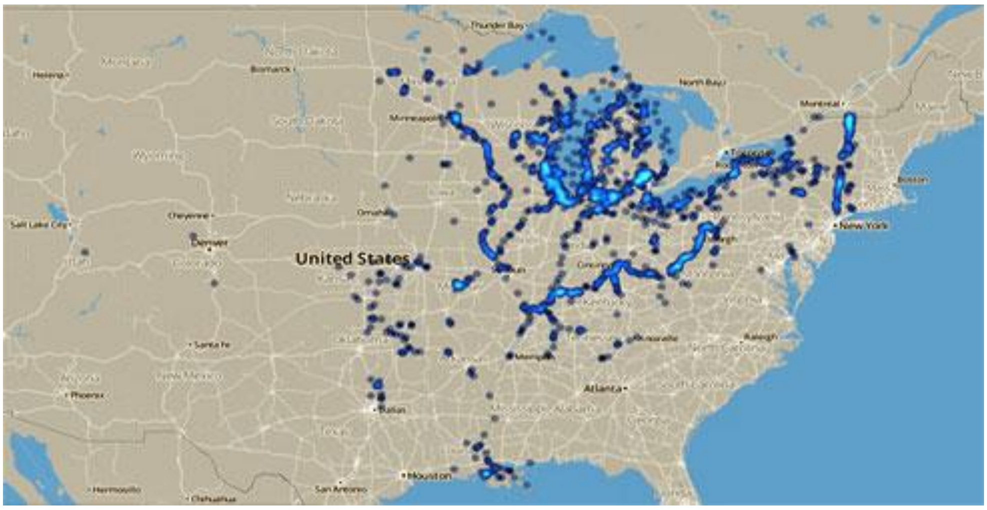


Figure 6. The zebra mussel *(Dreissena polymorpha)* invasion in the Great Lakes. – Source: https://www.nature.org/ourinitiatives/regions/northamerica/areas/greatlakes/explore/aquatic-invasive-species-maps.xml

- The killer shrimp *(Dikerogammarus villosus)* was found recently in the Great Lakes (United States of America) and Western Europe, provoking the extinction of different local species like native shrimps and young fish. This specie is native from Eastern Europe, mainly from the Danube River and its main characteristic is that it can survive in different conditions of temperatures, salinity and oxygen levels, being very aggressive in terms of colonization.
  The studies carried out to understand the way the killer shrimp arrived to the Great Lakes and Western Europe determine that they have achieved the migration thanks to the ballast water from ships (7).

Figure 7. The killer shrimp *(Dikerogammarus villosus).* - Source: https://upload.wikimedia.org/wikipedia/commons/4/42/Dikerogammarus_villosus_%288740859563%29.jpg

1.6 Geographic risk

The risk of invasion of non-local species can vary a lot depending on the region of the world due to the characteristics of the area. Some of the factors to be taken into account when understanding where can be a big concentration of invasive species are (8):

- Concentration of ships in hub ports.
- Level of similarity (in terms of environment) between the origin port and the destination.
- Level of invasive species already living in a specific region provoking a habitat disturbance.
- Water temperature and salinity of origin and destination of the ballast water.

In general, considering above factors, it exists high risk of spreading of invasive species when the ballast water is loaded in a region with very similar characteristics to the seawater of destination. The risk of invasion clearly decreases when the characteristics are different, and it almost disappears when the characteristics are completely different. For example, an invasive specie is likely to be spread if it is ballasted in Baltic Sea and de-ballasted in the Pacific Coast due to their similarities (both of them have cold water). On the contrary, the probabilities of spreading a specie ballasted in the Baltic Sea and de-ballasted in the tropics is very low as the likelihood of surveying for the specie is very low.

In Figure 8, it is represented the number of known harmful alien species of the North hemisphere. We can observe that where more harmful alien species can be found is the Mediterranean Sea, West Coast of the United States, water from around Great Britain and the islands of the North Pacific (Hawaii).

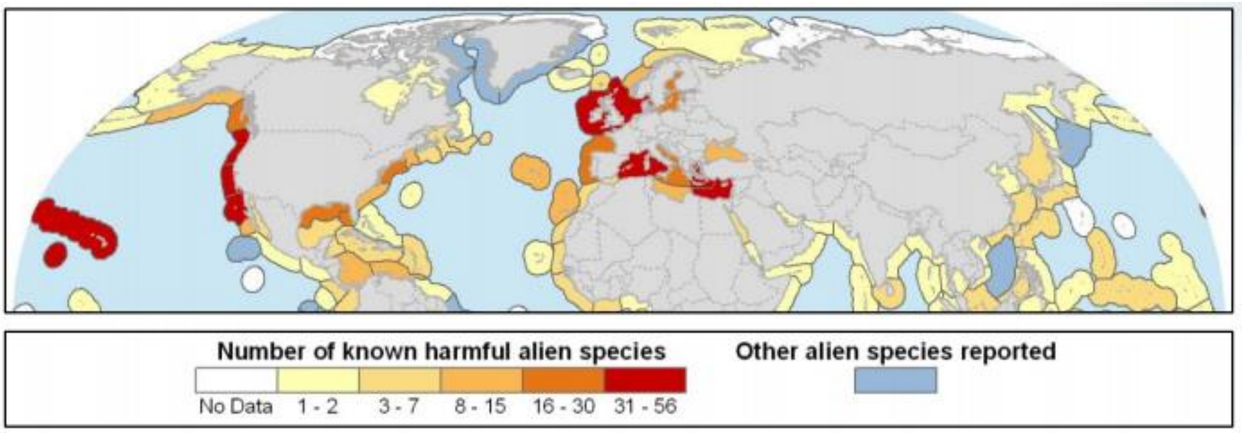


Figure 8. Number of known harmful alien species. - Source: http://www.imo.org/en/OurWork/Environment/MajorProjects/Documents/EBRD%20BWM_Infrastructure_Investment_Guidance.pdf

In the case of the Mediterranean Sea, it is considered that it has high probability of spread of an invasive specie if the seawater was ballasted in the Black Sea or the Caspian Sea (that have similar environment and warm temperature). Medium probability is considered when water was ballasted in cold temperature seas (Baltic Sea and Pacific Coast) or the tropics. Finally, low risk in Mediterranean Sea is considered when ballast water comes from the Arctic or the Antarctic as the different of temperature is too high and the organisms would die naturally without the need of any treatment.

The risk profile of the Mediterranean Sea that, as we have seen, has a big number of known harmful alien species is the following (8):

- The traffic of ship is very high considering the dimensions of the sea.
- There are many farms of fish and shellfish in lagoons or bays of the sea.
- The quality of the water is lower than some years ago due to bad treatment of grey waters and the reduction of nutrients in the seawater.
- Overfishing is threatening the biodiversity of marine ecosystems and the habitat of local species has been reduced.

In conclusion, it is very important for the Mediterranean Sea to have a proper control of the ballast water discharged as it can represent a high risk for the local environment. For this reason, it is essential to carry out different inspections like strict Port State Control to minimize the risk of the appearance of new invasive species.

1.7 Impact of BW in different projects

The impact of ballast water is mainly caused by vessels that need to adjust their stability when sailing from one port to the other or when loading/unloading cargo. It exists also other types of cases that it also takes places ballasting or de-ballasting and can also cause the spreading of an alien specie into local waters. This would be the following cases (8):

- Construction of a port facility: when constructing a new port facility, it is required the assistance of vessels for dredging that can arrive to the port from different regions of the world. When dredging, as they load sand/stones from the seabed, they require to de-ballast for improving their stability. In this process, they can deliver alien species in the local water of the port. In the same way, when sailing to the origin port, they can transfer species from the region the dredge has been working in.
- Increase of traffic in a specific port: the increase of traffic will cause also an increase of the regions where the vessels come from, increasing the risk of new species coming from ballast waters from ships.
- Expansion of a specific port: the growth in size of a port will let bigger vessels to call that port. In this way, usually the vessels as bigger they are, bigger is the ballast water that they require for improving their stability. This would clearly affect the exposure of the local environment to other species.

In conclusion, it is not only important to control the ballast water from typical merchant ships but also the vessels or other projects that can affect the local environment occasionally. In this way, dredges and other type of service vessels can represent also a threat for the environment if it is not controlled the ballast water properly.

Chapter 2. Ballast Water Management Convention

2.1 Introduction

Due to the use of ballast water from ships with steel hulls, which traffic has been increased due to worldwide trade, there have been many negative effects associated to it. According to International Maritime Organization (OMI), quantitative data proves that the bio-invasion is increasing to alarming levels, being in danger not only the marine ecosystems but also the human life (because of the food that is affected mainly). Moreover, it is thought that the peak has not been achieved yet and the problem will still continue growing in the future.

To minimize the effects caused by the ballast water, IMO drove reforms on the regulation for controlling the discharge of BW from ships. The 13th February 2004 it was adopted the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM) which aim is to establish standards and procedures regarding the control and management of ballast water from ships (9).

According to Ballast Water Management Convention, in international traffic all ships are required to manage their BW and sediments as stated by the standards, depending on the Ship Ballast Water Management plan. Furthermore, it needs to be recorded the BW in the ballast water record book and it need to be carried an international ballast water management certificate. In general, due to the standards specified in the Convention, most ships need to carry an on-board ballast water treatment system to minimize the effect of the BW on the marine environment.

The Convention entered into force the 8th September 2017, having a total of 73 States signing it and representing 75.35% of worldwide merchant shipping tonnage, according to last update of the statics (10).

2.2 Regulation (11)

The Convention is divided into different articles and annex. It has on following structure:

- General obligations (article 4): it endeavours all parties involved to apply and give effect of the provisions agreed in the Convention so as to minimize the transfer of dangerous organisms through the use of ballast water and sediments. Moreover, it specifies that each party involved (countries) can apply more restrictive actions to eliminate the effect of ballast water, prevent the harm to the environment, the human health...

- Reception facilities (article 5): all Parties must ensure that their ports/terminals which are in charge of the cleaning or repair of the ballast tanks of the ships, have suitable reception facilities for the remains and sediments.
- Research and monitoring (article 6): all Parties should try to encourage the scientific research about ballast water and its monitoring.
- Survey, certification and inspection (Article 7, 9, 12): all ships under the Convention must be surveyed and certified, inspected by means of Port State Control usual inspections and different parties will ensure that ships which represent a threat do not discharge Ballast Water until the problem has been solved or the threat disappears.
- Technical assistance (article 13): there must be co-operation among different parties involved on the control and management of ballast water and sediments from ships. This co-operation consists not only on technical assistance but also training on personnel.
- Annex – Section A General Provisions: it contains some definitions, applications and exemptions about the application of the Convention.
- Annex – Section B Management and control requirements for Ships: ships are required to follow a Ballast Water Management Plan (approved by official Administration), having a specific one for each ship. In addition, each ship must have a Ballast Water Record Book. Finally, it includes specific requirements about ballast water management (as exchange of ballast water should whenever possible take place at least 200 nautical miles from ashore and 200 metres in depth).
- Annex – Section C Additional measures: different States affected by a national regulation about Ballast Water should be communicated about new regulation. Furthermore, for a new national measure, it needs to be communicated to IMO at least 6 months before its implementation.
- Annex – Section D Standards for Ballast Water Management: exchange of ballast water must be performed according to standards.

2.2.1 Regulation D-1 Ballast Water Exchange Standard

It exists two different ballast water management standards (D-1 and D-2) that need to be complied according to the requirement of the BWM Convention. Those standards are probably most important points of the Convention.

For vessels built before the date of entry in force of the Convention, it is required to comply at least with regulation of D-1. For vessels built after the date of entry in force of the Convention (new ships), it is required to comply with D-2 standard. Moreover, those vessels built before the entry in force, will be forced to meet D-2 standards during following years as we will see in this chapter.

For complying with the standards of D-1, the ballast water exchange needs to be carried out in open sea, away from coastal area (about 200 nautical miles from shore), and with a minimum depth of 200 metres (12). The idea of this regulation is that invasive species are less likely to survive.

Moreover, vessels need to exchange ballast water with an efficiency of at least 95 percent volumetric exchange of ballast water (9).

Finally, it is required that for exchanging ballast water through the pumping-trough method, the pumping needs to be done three times the volume of each ballast water tank. This methodology can be avoided if vessel can prove that she can met the standards commented on previous paragraph about the 95 percent volumetric exchange (9).

It is important to remark that it exists some big areas where it does not exist the minimum miles or the depth required for the exchange of ballast water. This is the case of the North Sea that it is applied an exemption of the requirements of the D-1 standards. If a vessel is on a voyage between two different ports in the North Sea, she needs to exchange Ballast Water on some designated areas that were index ARI (Aggregate Risk Index) is less than 0.75, including through the Traffic Separations Scheme.

In Figure 9, it is shown a map of the designated exchange areas of ballast water in the North Sea (in orange stripes, the areas where ARI is higher than 0.75) (13):

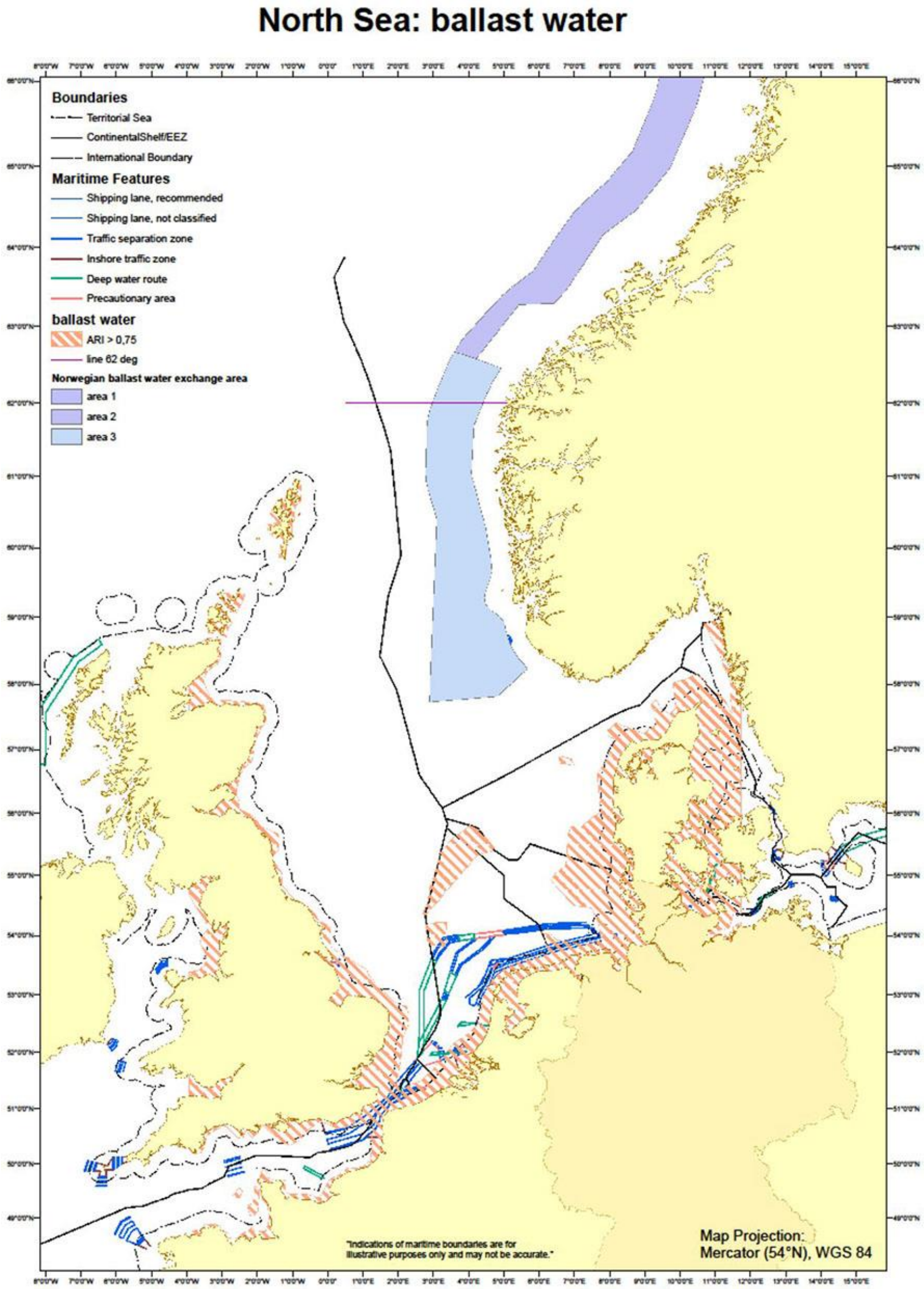


Figure 9. the designated exchange areas of ballast water in the North Sea. – Source: https://www.mea-nl.com

2.2.2 Regulation D-2 Ballast Water Performance Standard

Regulation D-2 specifies that the maximum rate of viable organisms to be discharge during the exchange of ballast water and its maximum size allowed. Therefore, Regulation D-2 sets the standards for the treatment of Ballast Water.

The MEPC in its 71st session (MEPC71) set that treated ballast water discharged must have (13):

- Less than 10 viable organisms per cubic metre greater than or equal to 50 micrometres in minimum dimension per cubic meter.
- Less than 10 viable organisms per millilitre less than 50 micrometres in minimum dimension and greater than or equal to 10 micrometres in minimum dimension per millilitre.
- For microbes (as per human health standards):
    - Toxicogenic Vibrio cholerae (O1 and O139) with less than 1 colony forming unit (cfu) per 100 millilitres or less than 1 cfu per 1 gram (wet weight) zooplankton samples.
    - Escherichia coli less than 250 cfu per 100 millilitres.
    - Intestinal Enterococci less than 100 cfu per 100 milliliters.

Table 1 shows a summary of different microbes and its maximum concentration according to D-2 standards:

ORGANISM CATEGORY	REGULATION
Plankton > 50µm	<10 calls/m^3
Plankton 10 – 50µm	<10 calls/m^3
Toxicogenic Vibrio cholera (O1 and O139)	< 1 colony formint unit (CFU) / 100 ml or <1 CFU per 1 gram (wet weight)
Escherichia coli	<250 CFU / 100ml
Intestinal Enterococci	<100 CFU / 100ml

Table 1. Standards discharge of BW according to IMO D-2. – Source: author. Data extracted from IMO BWM Convention.

2.2.3 Regulation D-3 approval requirements for Ballast Water Management systems

Ballast Water Management systems need to be approved by the Administration taking into account the standards mentioned on D-1 standard or D-2 standard. For the approval, the systems must be considered safe for the vessel, her equipment and the crew (13).

Moreover, all approved systems must comply with the requirements of the *Code for approval of ballast water management systems* (BWMS Code) adopted by MEPC in April 2018, entering into force in October 2019 (14)[1].

To get the approval of a ballast water management system, it will need to be tested both ashore (dry dock for example) and at sea to prove that the technology is between the standards that the Convention specifies in D-2. The process of final approval of the system takes two years as during this period of time the system and the treatment is evaluated. The two years test has the purpose of assuring that it cannot represent any risk for the environment, the vessel, the resources or the health of humans.

2.2.4 Regulation D-4 Prototype Ballast Water Treatment technologies

For getting the final approval of the Ballast Water Treatment technologies, the treatment systems must be tested during a period of five years. After this time, it can be carried out a final assessment.

2.2.5 Regulation D-5 Review of Standards by the Organization

The standards of the Convention need to be reviewed constantly to ensure a safe and environmentally friendly discharge of the ballast water to avoid the spread of invasive spices.

2.3 Main requirements of the Convention

According to the Convention, following requirements for ships need to be applied (15):

- All ships must have on board a ballast water management plan and a ballast water record book.
- Ballast water and sediment management need to be carried out in all voyages without exception.
- Ships of 400 of gross tonnage (GT) and above (excluding floating platforms, floating storage vessels and floating production, storage, and offloading vessels) will have surveys and certification to obtain the International Ballast Water Management Certificate and to ensure a correct application of the Convention.
- All ships will need to choose whether carrying out a Ballast Water Exchange (BWE) complying the standards of the Convention or using an approved ballast water treatment system.

The International Ballast Water Management Certificate is issued by the Administration of the flag State and it certifies that the vessel is carrying out Ballast Water exchange in accordance with the BWM Convention. The certificate specifies which Standard (D-1 or D-2) is she complying and the expiration date of the certificate issued. The process for obtaining it is the following (16):

[1] Complete list of ballast water management systems approved by IMO can be found at following website: http://www.imo.org/en/OurWork/Environment/BallastWaterManagement/Documents/Table%20of%20BA%20FA%20TA%20updated%20May%202018.pdf

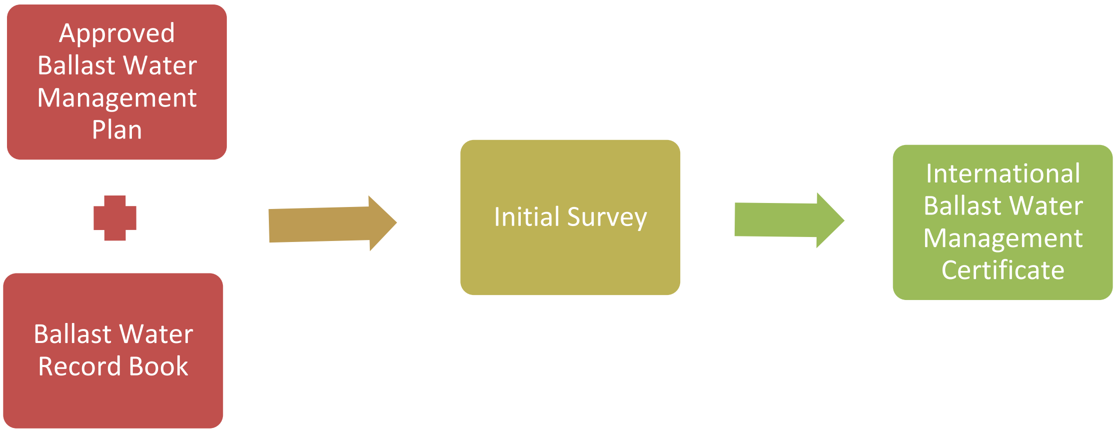


Figure 10. Obtention process of International Ballast Water Management Certificate. - Source: author.

2.4 Ballast Water and Sediments Management Plan (BWMP)

It is the document which includes all details regarding the methods for the discharge of the BW and the handling of the sediments produced on board. The procedures need to be followed according to regulation D-1 about exchange, or regulation D-2 about treatment and regulation B-5 about sediment management.

According to the International Convention for the Control and Management of Ships' Ballast Water and Sediments, it is compulsory to have a BWM Plan approved by an Administration (Regulation B-1) (11). The plan must be specific for each vessel and equipment (depending on which she has on board) (17).

The BWMP usually contains the following information (18) (19):

- Shore facilities locations where vessels can discharge remaining sediments or ballast water.
- Rules and regulations according to International law about different Port State Control.
- Operational procedure when ballasting or de-ballasting.
- Necessary conditions to carry out a ballast operation.
- When not to perform a ballast operation.
- Duties of the crew members while carrying out ballasting or de-ballasting.
- Sampling and treatment method for the ballast water being carried on board.
- Ballast water sampling points.
- Ballast water tank plan.
- Log keeping: a ballast log needs to be correctly updated to demonstrate to the arrival port that Ballast Water has been managed accurately.

2.5 Ballast Water Record Book

It is recorded all the information of a minimum period of two years of the operations of ballast water exchange. On the log book is recorded all the information regarding the ballast operations as (18):

- Date opt the ballast/de-ballasting.
- Tanks used for ballast.
- Position of the vessel when the operation takes place.
- Temperature of the ballast water loaded.
- Total quantity of ballast water exchanged.
- Salinity of the ballast water.
- Signature of the Master being responsible for the exchange operation.
- Remarks as any problem that could have happened during ballasting or de-ballasting.

Figure 11 is a typical form used for recording all the exchange of ballast water:

(A) Ballast Water Tanks or Cargo Holds		(B) Ballast Water Source			(C) Exchange						(D) Intended Victorian discharge port for ballast water		
								Empty/Refill ONLY	Flow-through/Dilution ONLY				
Tank	Full Tank Capacity (m^3)	BW uptake PORT	Uptake Date	Volume of ballast water taken up (m^3)	Exchange Location (Latitude/Longitude) Start (S) End (E)	Exchange Date & Time Start (S) End (E)	List Pumps Used (Pump Number) & current capacity m^3/hr	Residual volume when empty (m^3)	Volume pumped (m^3)	Percentage Exchanged	BW discharge port in Victoria	Discharge Date	Volume for discharge (m^3)
FPT	250	Port Botany	15/1/06	245	S: 35°05'S 151°02'E E: 36°10'S 150°10'E	S: 16/1/06 1045 E: 16/1/06 1145	Pump 1 500	10	NA	NA	Melbourne	17/1/06	240
					S: E: S: E:	S: E: S: E:							
					S: E: S: E: S: E:	S: E: S: E: S: E:							
					S: E: S: E:	S: E: S: E:							

BALLAST WATER TANK CODES: Forepeak = FPT Aftpeak = APT Double bottom = DB Bottom tank = BT Bottom side tank = BST Deep tank = DT Wing tank = WT Top side tank = TST Cargo hold = CH Heeling tank = HT
Water ballast tank = WBT Port = P Starboard = S Centre = C Bilge = BGT Other = O (specify)

Figure 11. Standard Ballast Water Record Book form. – Source: https://www.intertanko.com/upload/Tim/Victoria%20Record%20Log.pdf

2.6 Compliance of the requirements of the Convention

There are two different ways of proving that a vessel is complying with the regulations that are stated on the BW Convention (12):

- Documentary evidence: thanks to the Ballast Water Record Book it is very easy to prove in front of the different authorities that a vessel has been recording all the information regarding the exchange of ballast water.
- Technical evidence: it can be proved thanks to the belonging of the International Ballast Water Management Certificate or if it is expired, thanks to the survey for the renewal of the Certificate.

2.7 Type of vessels exceptions from the application of the Convention

There are some vessels that do not need to comply with the requirements of the convention due to their size, design or their purpose (12):

- Ships which cannot carry ballast water (not designed with ballast tanks).
- Ships of a party that only operate in the jurisdiction of one party, except if the party believes that the discharge of ballast water from those ships can represent a threat for the environment, the human health, the resources or to adjacent states.
- Ships operating only in waters of one party jurisdiction that also operates in high seas where the exchange of ballast water cannot represent any threat as the ones mentioned above.
- Special purpose vessels as warships, naval auxiliary ships or other vessels operated by the states.
- Vessels that can carry ballast water in sealed tanks permanently.

2.8 Application of the Convention to existing and newly built vessels

The situation is clearly different among existing vessels that do not have any treatment technology on board to newly built vessels. For the newly built ships after the date intro force of the Convention (8th September 2017), it is required to meet the standards and to have an approved BWM System on board on the delivery of the vessel.

For existing ships, the regulation is different as they need to modify their systems for the installation of the treatment technology. For this reason, the Convention set the following schedule for the implementation of the BWMS (MEPC71) (20):

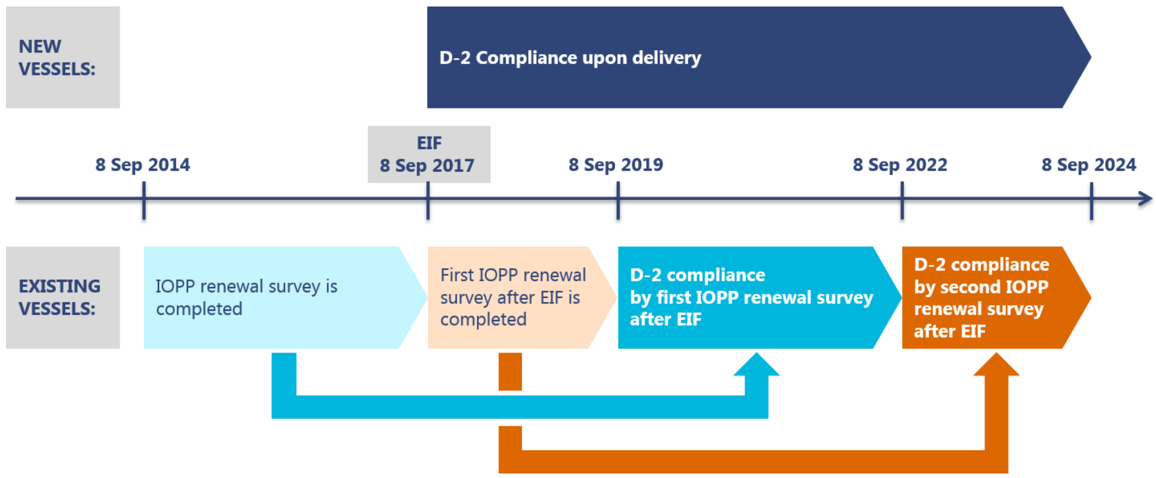


Figure 12. schedule for the implementation of the BWMS. – Source: http://www.gard.no/Content/23673248/BWM.png

As we can see, existing ships must comply with the first International Oil Pollution Prevention Certificate (IOPP certificate) renewal up to the 8th of September 2019 (two years after the entry in force date of the Convention). For existing vessels that last IOPP renewal survey was done between 8th of September 2014 and 7th September 2017, the vessel must have working a BWMS at next IOPP renewal survey or after the entry in force date of the Convention.

Finally, those vessels that do not need any IOPP renewal (ships of less than 400 GT or oil tankers of less than 150 GT) that were built before 8th September 2017, must comply with the standard D-2 before 8th September 2024. Therefore, all vessels where the Convention is applicable will have on board an approved BWMS complying D-2 standards no later than 8th September 2024.

In Figure 13, there is a summary of the difference among new build and existing ships :

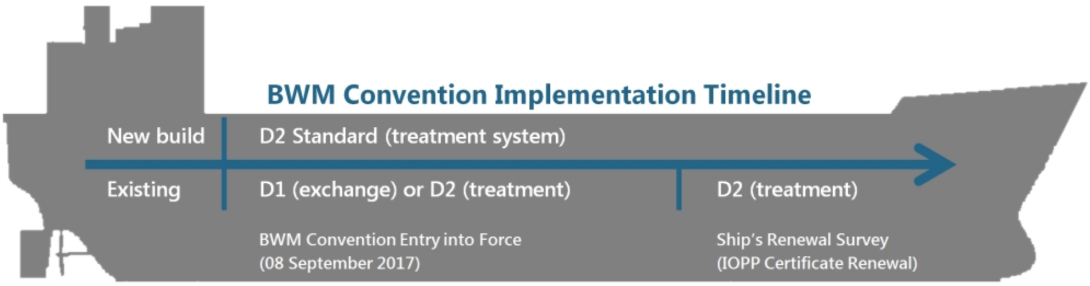


Figure 13. Differences for the appliance of the BWM Convention among new build and existing ships. - Source: http://www.abpmer.co.uk/buzz/ballast-water-management-convention-d-2-compliance-update/

2.9 International Oil Pollution Prevention Certificate (IOPP Certificate)

Despite the IOPP Certificate is not directly affected by the BWM Convention, it can represent the correct compliance of the implementation of D-2 on board the vessel, as we have seen during this chapter.

IOPP Certificate is a compulsory certificate for Oil tankers of 150 GT or above (as the risk of pollution is higher) and for vessels of 400 GT or above that is issued by the Administration or an authorized organization. The Certificate is included on The International Convention for the Prevention of Pollution from Ships (MARPOL). The purpose of the certificate is to prove with an international document that the ship is complying with the requirements stated in the Annex I of the MARPOL. In general, it is surveyed different parts of the vessel where there can be any risk of oil pollution like the structure, fittings, materials, different systems on board…

After the initial survey for the issuance of the certificate, the certificate must be renewed by a periodical survey every 5 years maximum. Moreover, there can be non-planned surveys or intermediate survey between these 5 years (21).

About main information that appears on the Certificate, it is following (22):

- Particulars of the ship: Name of the ship, IMO number, Port of Registry, Gross Tonnage, Date of build, Keel laying date…
- Equipment for the control of oil discharge from machinery space bilge and oil fuel tanks: carriage of ballast water in oil fuel tanks, oil filtering, approval standards, means of retention of oily residues, shipboard oil pollution emergency plan…

2.10 Action of EMSA and Mediterranean regional strategy for the appliance of the BWM Convention

EMSA is the European Maritime Safety Agency. It is an agency of the European Union created with the aim of reducing the risk of maritime accidents, reducing the pollution by ships and to assist European Commission and Member States in the development of legislation regarding mentioned issues. (among other purposes). Therefore, EMSA has also the purpose for the reduction of pollution from ballast water, understanding as pollution the introduction of invasive species in a third habitat.

Regarding the control of ballast water treatment from ships, currently it does not exist any European law that controls directly the problem of BWM. At the moment, it does only exist the Regulation (EU) No 1143/2014 which only mention the BWM Convention as an applicable measure for reducing the invasive species spread by ships of European flag. For this reason, it is considered that, up to now, EMSA has only helped European countries to implement BWM Convention without applying or proposing any other stricter regulation regarding ballast water and treatment technologies. Anyway, EMSA was one of most important parties for driving and pushing for a ballast water international regulation and was in a full-time cooperation with the International Maritime Organization when starting to write down the BWM Convention.

Finally, it is important to remark that despite it is not driven from EMSA directly, it exists a regional strategy in the Mediterranean for the control of ballast water. The Mediterranean Strategy on Ship's BWM was prepared by The Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC) from 2008 to 2011and was adopted in the 17th ordinary meeting of the Contracting Parties in Barcelona Convention in February 2012). This strategy included some important issues to be controlled by each party regarding ballast water control like: strategic priorities and actions for BW control in the region, an action plan from 2011 up to 2015, launching of a regional system for the monitoring and control of BW, common regional information system regarding the invasive species… (23)

Chapter 3. Treatment technologies

3.1 Introduction to BWM Systems

BWM Systems (BWMS) have become very important for shipping operators which need to comply with the regulations of IMO, as the Ballast Water Management Convention. For this reason, it exists many different systems for treating the ballast water and to avoid exceeding the pollution that the regulation establishes (24).

There are many factors that need to be taken into account when implementing a BWMS into a ship. Most important are following ones (25):

- Safety of the crew.
- Friendliness with the environment.
- Cost of installation and its maintenance.
- Capability to minimize the percentage of organisms in ballast water.
- Lack of difficulty so as to install it.
- Space on board (depending on the type of ship, her dimensions...).

Depending on all those factors, ship operators usually decides which systems suits best to their vessels and implement the one that is more useful for them. It exists following types of technologies used for the treatment of ballast waters (despite vessels usually use 2 or more technologies to ensure to comply the standards established by IMO):

- Deoxygenation treatment
- Filtration Systems (physical)
- Acoustic (cavitation treatment)
- Chemical Disinfection (oxidizing and non-oxidizing biocides)
- Ultra-violet treatment
- Heat (thermal treatment)
- Electric pulse/pulse plasma systems
- Magnetic Field Treatment

3.2 Physical separation or filtration systems

These types of systems are those which do not use any type of chemicals and they separate solid particles using sedimentation or filtration. Thanks to this method, most of the particles (mostly the biggest one) can be separated and the impact of the ballast water from the ship is reduced when discharging it. The idea is that once the solid particles/organisms are separated, they are treated on board before it is discharging or they are discharged in the area where the ballast water was taken.

3.2.1 Hydrocyclone

It consists on a high velocity centrifugal that is used for separating the solids from the water due to the centrifugal force. It is not difficult to install and use on the ship as it is a static system (it does not have any moving part). Main problem for the hydrocyclone is that it usually cannot separate the smallest organisms, not being very efficient sometimes according to different studies (26).

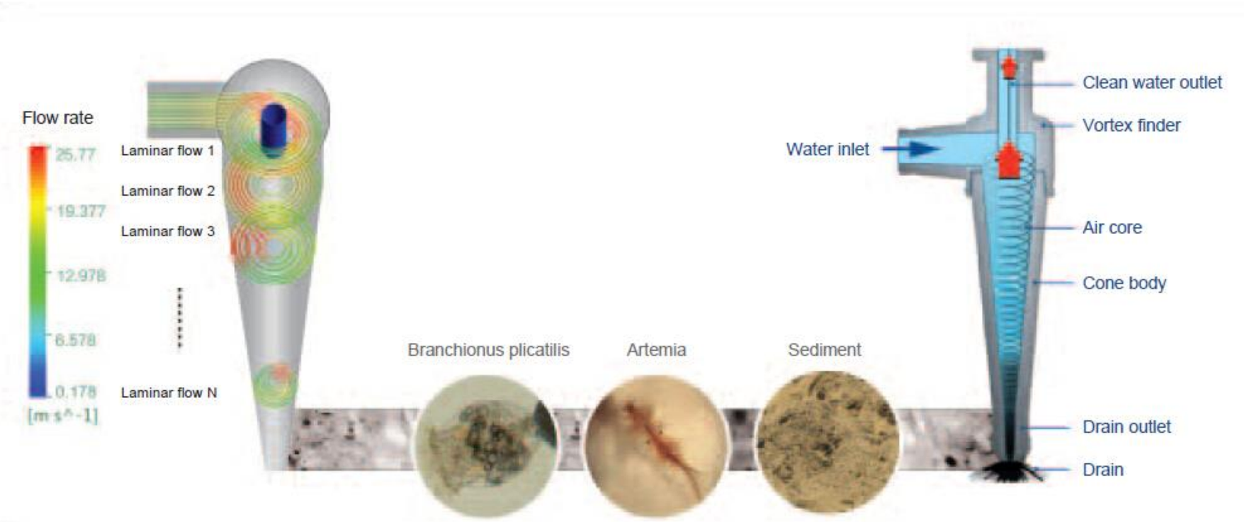


Figure 14. Hydrocyclone process. - Source: http://www.hiseamarine.com/ballast-water-treatment-system-4643.html

3.2.2 Screens

It is used some screen filters which can delete solid particles (organisms) that are suspended on the ballast water. It is a very effective system and is highly recommended due to its eco-friendliness as it does not use any type of chemicals which can damage the environment. It exists both fixed and movable screens. As it consists on a filter that separates the solid particles from water, it has the inconvenient that some small organisms cannot be removed effectively.

For this reason, some studies prove that this method is not enough to effectively remove all solid organisms and it is not sufficient to comply with the minimum requirements of IMO standards (27).

Figure 15. Screen filter. - Source: http://www.cross.com.gr/wp-content/uploads/2012/05/Filtersafe-1.png

3.2.3 Media filters

They are effective mostly for the smallest size of particles, being able to remove organisms of less than 1µm in size (other physical methods can only remove organisms of 50µm in size). Crumb rubber filter (compressible media filter) is highly recommended for vessels due to its size (as the material is compressed) and its density. The conventional media filter is the granular filtration (26).

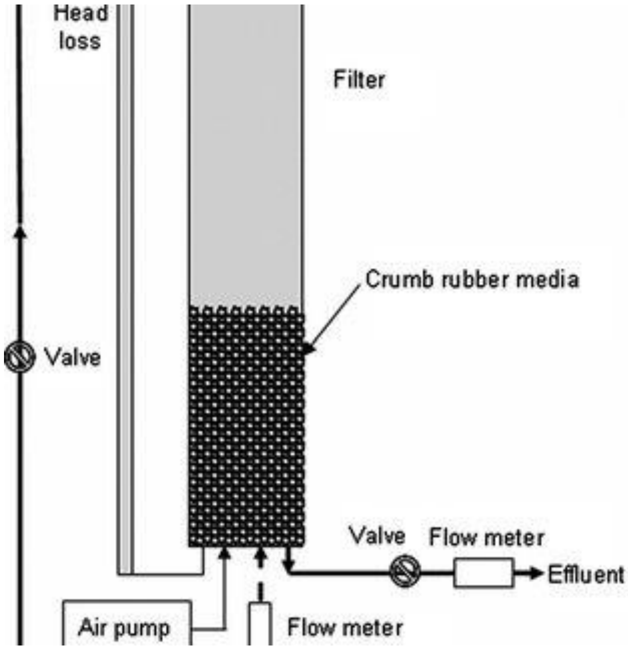


Figure 16. Process of granular filtration. - Source: https://www.researchgate.net/figure/Experimental-setup-of-the-crumb-rubber-filter_fig1_312084413

3.2.4 Coagulation

It is a method used for deleting the smallest particles that cannot be removed using other methods as the filtration or the hydrocyclone. Coagulation is used before the filtration process so as to merge the small solid particles and achieve a bigger particle, being easier to separate it from the ballast water thanks to filtration or any other process. The process of creating bigger particles is known as flocculation, and the big particles are called “flocs”. It is usually used powder as magnetite or sand in order to cause the flocculation.

Thanks to coagulation, the efficiency of the other methods increases considerably and most of the particles can be removed successfully. Main disadvantage for coagulation is that it requires more space onboard as it is needed an extra tank for carrying it out (28).

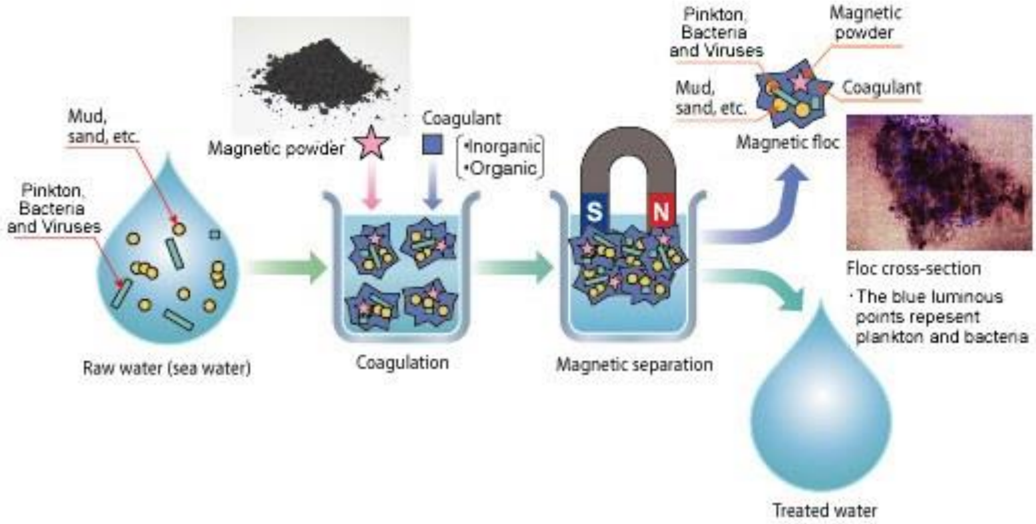


Figure 17. Coagulation process. - Source: https://www.marineinsight.com/wp-content/uploads/2013/06/coagulation.jpg

3.3 Magnetic field treatment

Magnetic field treatment is applied once the coagulation process is performed. Thanks to the magnetic powder that is used for creating the flocs, it can be applied a magnetic force to attract the flocs and separate them from the water. The magnetic field is generated by magnetic discs. In Figure 17, it is shown how magnetic field treatment works and how the solid particles are separated from the treated water to avoid the pollution when de-ballasting.

3.4 Chemical Disinfection Ballast Water Treatment

It consists on the appliance of chemicals to take away the invasive species from the ballast water that has been loaded. For the removal of the organisms, it is used biocides which act as disinfectants. Those biocides are specially tested for marine organisms and the efficiency is very high. Furthermore, they are degradable, not representing a danger for the environment as they are not considered toxic substances (29).

It exists two types of biocides depending on its function:

3.4.1 Oxidizing biocides

They are considered general disinfectants which destroy the cells membrane or nuclear acids of the microorganisms. Most common types of oxidizing biocides are (30)(31):

- Ozone gas: bubbles of ozone as are released to the water. Once it is dissolved in the water, it reacts with other chemicals and destroy the organisms. Main disadvantage is that it is highly pollutant and is toxic to human, being a danger for the human health,
- Chlorine: it is a gas that can be produced by on the ship from seawater. Once it is released into the ballast water, it can destroy the microorganisms as it is considered to be a very dangerous gas. For example, it can cause to human irritation on the respiratory system, cause cancer, burn the skin in case of being in contact with it…
- Peracetic acid and hydrogen peroxide: when it is diluted in water it can destroy the cell walls of the microorganisms that inhabit in the ballast water tanks. It is also harmful for the human health.

3.4.2 Non-Oxidizing biocides

When dissolving them on the water they interfere directly with important functions of the organisms such as reproduction, neurological processes or metabolism. They usually do not act immediately so for a good treatment of the ballast water they need to be applied on the beginning of the voyage. As it requires some days to have an effect, non-oxidizing biocides are not the best option for removing invasive species from water, specially if vessels are sailing on short voyages.

Main example of non-oxidizing biocide is the gluteraldehyde. This biocide is typically used for the sterilization of medical equipment, destroying many types of organisms that can also be found on ballast waters.

An alternative non-oxidizing biocide is the ”SeaKleen”, a mixture of Vitamin K3, bisulfite and naphthoquinone. Main problem for “SeaKleen” is that it is still not clear that it have a correct effect on the different species that can be encountered on the ballast water (26).

3.5 Electric pulse and plasma treatment

They are considered an environmentally friendly, not expensive and easy installation systems for the treatment of ballast water. Thanks to both methods, it is avoided the use of chemicals or other substances that can be dangerous for the environment. It is considered that both methods have similar results and none of them is considered better than the other.

The electric pulse consists on the appliance of pulses to the ballast water so as to kill the microorganisms that have been loaded on the tanks. The pulses are generated by two metal electrodes that can generate a high power current that are able to transmit in different densities and pressures (32). Electric pulse has been studied by EcoSeaSafe project and it concludes that it can be a very useful and good cost-effective method (33).

For electric plasma treatment, an energy pulse is generated by a mechanism placed inside the water that generates a plasma arc which kills the microorganisms living on the ballast water.

Main disadvantages for these methods are that it can have an impact on the operations of the ship, the staff must be properly trained and it is a technology that is still under investigation (35). Probably it needs to still pass some years until electric pulse and plasma treatment can be considered a good method for the treatment of ballast water.

3.6 Heat treatment

The aim of the treatment is to increase the temperature of the ballast water until the microorganisms are killed. Main benefit of this method is that it can be used a heating system that is already in use in the vessel so as to raise the temperature of the water in the ballast tanks. In the opposite direction, it can be used the ballast water to cool down the temperature of the engines or other systems of the vessel.

Main advantage is that there is no need of using any external substance and it only requires to vary the temperature of the water to ensure that the organisms are killed and the ballast water becomes safe for the de-ballasting.

Main disadvantage for this method is that it usually requires lot of time to kill the microorganisms, being also harmful due to the corrosion in the tanks (34).

3.7 Deoxygenation

The idea of the method is to reduce the level of oxygen on the water of the ballast tanks so as to destroy the microorganisms by asphyxiation. For the deoxygenation of the water it is usually used nitrogen or different inert gases that can achieve low levels of oxygen (36).

Main advantage of the method is that it is avoided the corrosion of the ballast tanks, increasing its useful life. Moreover, it is an environmentally friendly method and it is a good option for saving money (as no extra space is needed and the tanks need less maintenance).

Main disadvantage of this method is that it usually last between two and four days to asphyxiate the microorganisms, not being a very fast method if it requires an urgent disinfection of the ballast water (short transit time for example).

3.8 Cavitation or Ultrasonic treatment

It consists on the usage of acoustic signals to destroy the microorganisms of the ballast waters. For this purpose, ultrasonic energy is applied to the ballast water, producing high energy ultrasound that kills the cells of the microorganisms. For the optimal effectiveness of this method, it is necessary to be combined with any other system of treatment of the ballast water (25).

Main benefit of the cavitation or ultrasonic treatment is that it is not necessary to apply chemicals which can represent a danger for the environment. Moreover, it does not require to install any important extra part to the ship, not being considered an expensive method to be used (37).

3.9 Ultra-violet Treatment method

It consists on the usage of UV lamps that covers the walls of a chamber where the water passes through. It is applied UV-C Rays which can destroy the microorganisms thanks to its ease to penetrate the DNA of the organisms and destroying or modifying their cell's metabolism. The result of modifying the DNA it that it is avoided the reproduction of the microorganisms (38).

Main benefit of using ultra-violet treatment method is that it is considered an environmentally friendly method (it does not use neither toxic compounds nor chemicals) (39). In addition, it can work properly in different levels not only of salinity but also of water temperatures.

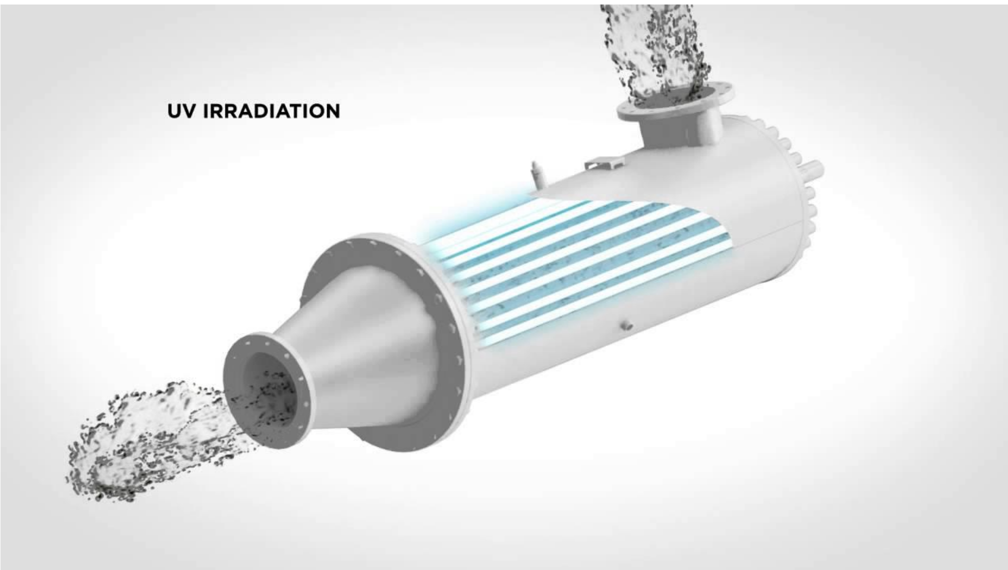


Figure 18. UV radiation process. - Source: https://www.youtube.com/watch?v=AnxKOXiyQkU

Main disadvantage of UV Irradiation is that it can show problems when working with turbid water where it is difficult for the UV rays to penetrate into the organisms that the ballast water contains.

3.10 Example of Ballast Water treatment system on ships

After having explained the different treatment technologies that exist for reducing the invasion of alien species into a specific environment, we need to point out that it is never used one method for the treatment of the ballast water. In most of the cases, it is used 2 different technologies that when working together can maximize the efficiency of the system. As we will see in Chapter 5, lots of the systems installed on board use filtration (or another type of physical separation) and another system (chemical disinfection, for example).

For this reason, when we have a look to a real BWM System of a ship we will see that the treatment of ballast water is usually carried out in different steps, depending on the number of treatment technologies that combined form the entire system.

Chapter 4. Process of study, installation and control of BW Management System

4.1 Factors to be considered

When choosing the type of BWMS for a vessel, many factors are considered to decide which system suits best for a specific vessel. For this reason, every vessel needs to be studied individually to optimize the design of the treatment system chosen and optimize the installation of the system.

4.1.1 Ship type and purposes

It is essential to know which type of vessel it is and where will she operate. For example, the needs of a vessel will not be the same whether she sails only through the Mediterranean or she sails through different oceans where there can be many different types of organisms from one to the other.

It is also important to know in advance which ports will the vessel calls as there are some ports that have specific regulations about ballast water that can represent a problem for the shipowner if they do not take it into account in advance.

Furthermore, each surrounding of the ports is different, having different characteristics such water salinity, temperature or turbidity. As we will explain on following chapters of the work, there are some types of BWM systems that can present some difficulties in the treatment of ballast water if the turbidity is very high (ultra violet system), high levels of salinity (electrolytic system) or low temperatures (electrolytic system).

Finally, and a very important factor, is to know the vessel size and its dependence on the ballast tanks for their stability. Depending on the size and type of cargo there can be some BWM systems that cannot be used as their pumping rate is too low, needing lot of time for carrying out the ballasting or de-ballasting of the ship and forcing the vessels to lose many hours on the operation of optimizing their stability (40).

In Table 2, it shows representative ballast capacity and representative pumping rates depending on the type of vessel. As we can observe, in general, bulk carriers and tanker vessels need more powerful BWM Systems (in terms of pumping rate and capacity of tanks) as for them it is very important to use ballast water to increase the stability.

Vessel catergory	Vessel Type	Representative Ballast Capacity (m^3)	Respresentative Pump Rate (m^3/h)
High Ballast Dependent Vessels	**Bulk Carriers**		
	Handy	18,000	1,300
	Panamax	35,000	1,800
	Capesize	65,000	3,000
	Tankers		
	Handy	6,500	1,100
	Handymax-Aframax	31,000	2,500
	Suezmax	54,000	3,125
	VLCC	90,000	5,000
	ULCC	95,000	5,800
	Containerships		
Low Ballast Dependent Vessels	Feeder	3,000	250
	Feedermax	3,500	400
	Handy	8,000	400
	Subpanamax	14,000	500
	Panamax	17,000	500
	Postpanamax	20,000	750
	Other vessels		
	Chemical Carriers	11,000	600
	Passenger Ships	3,000	250
	General Cargo	4,500	400
	Ro/ro	8,000	400
	Combination Vessels	7,000	400

Table 2. Representative BW capacity and pumping rate depending on type of vessel. – Source: remake made by author from https://ww2.eagle.org/content/dam/eagle/advisories-and-debriefs/ABS_BWT_Advisory14312.pdf

4.1.2 Installation area and space needed

The space needed for installation if very important when choosing the most suitable ballast water management system. The size of the system clearly increases once the capacity and pumping rate increases. Therefore, as bigger the vessel is, bigger the system needed will be. In general, ballast pipes can have a diameter from 250 mm up to 500mm (40).

For avoiding the use of extra space, the system is usually installed close to the ballast pump to avoid using extra pipes and connections to another are of the ship. Moreover, it is compulsory to take into account that the system needs to be placed in a non-gas dangerous area (as the system has electrical equipment) or the system needs to be gas safe (41).

4.1.3 Costs

The costs always have a very important role in every installation that a vessel needs. For this reason, the idea is to reduce the costs whenever possible while trying to optimize the efficiency of the system. It is said that there are 4 different steps to be taken into account while talking about costs of the BWM Systems (40):

1. BWMS equipment: the cost of the equipment can vary depending on the manufacturer or the supplier. In addition, the cost of the equipment depends clearly on the ballast water needed to be treated and its power, being more expensive those equipments that are installed on board vessels that need big ballast water capacities and pumping rates.
2. Design and Engineering: The cost of the design is usually related to the complexity of the installation. It needs to be taken into account the where the system will be installed (
3. Installation: The cost will be higher if there is not a big space for its installation and an extra space is needed, usually needing to move other equipment or changing the purpose of some areas. Conversely, if the space where the system is big enough, the installation will not have any extra cost.
4. Operation: depending on the system used it can be highly reduced the cost while using the system. When we talk about operational cost it is the price we need to invest every 1,000m^3 of ballast water treated, for example (41). This cost is directly related to consumption of energy (fuel). At last, it is important to take into account the cost of maintenance as there are many systems that require a very exhaustive maintenance and the cost can clearly increase.

It has also to be mentioned the lifecycle costs, which takes into account how long the system will be used and is very important as a big initial investment can signify a reduction of the cost on the following years (42).

4.1.4 Control systems and power consumption

One of the main factors to bear in mind when talking about costs is the power consumption. Depending on the type of system and the needs of the vessel, the treatment system will require high levels of power, which will also increase the costs (43). If the own generators of the ship are not enough for providing sufficient electrical power, it will require to implement an upgrade on the power generation of the vessel, a process that is very expensive and increases clearly the levels of exhaust emissions (40).

About the control systems, it is important to connect the treatment system to the different panels and interfaces that the crew is using for a proper control. For this aim, it is installed an automated system connected to auxiliary services so as to, for example, ring an alarm in case of malfunction and to let the crew react properly.

4.1.5 Stability of the vessel

The installation of the treatment system can represent a change on the stability of the vessel, modifying the centre of gravity. For this reason, once an installation of a BWM system is done, it is required to modify the stability booklet as there can be a variation of weight up to 2%.

Moreover, it will be required to make again all calculations regarding the stability and a new watertight integrity plan to avoid any risk once sailing, berthed or at anchorage. Finally, if the change can represent a variation on the forces of the vessel, new structural drawings will be needed (40).

4.1.6 Safety of the equipment

If the treatment system is installed in a new compartment, special measures about fire safety need to be implemented to ensure that the compartment complies with the regulations.

4.2 Installation of BWM System

The process of installation of a BW treatment system can vary a lot from one existing vessel to a newbuild ship. In the first case, the difficulty is much higher as retrofitting a BWM System on a existing ship implies that as it was not considered once constructing the ship, there needs to be an adaptation of the system to current circumstances and systems of the ship. For a existing ship, it usually takes two weeks for the retrofit in the dockyard, being indispensable not to have any delay as it can signify a lost income for ship owner. For its installation, it usually takes part following partners: shipowners, the supplier of the BWM System, an engineering firm in charge of the study and shipyard in charge of installing the system.

In the second case, the range of options are higher. In the circumstances of a newbuild ship, the design of the ship is thought taking into account the BWM System that the specific vessel will require from the beginning. For a newbuild ship, the installation usually takes some months and any change can be carried out without affecting the operations of the vessel (42).

We will explain the installation of a retrofit BWM System on an existing ship as the difficulty is higher. Despite there are no official stages or phases about the installation of BWM System, we will divide it in following different phases:

- Vessel survey.
- Feasibility study.
- Retrofit engineering.
- Pre-fabrication.
- Installation.
- Verification of the system.

4.2.1 Phase 1: Vessel survey

The initial phase consists on the study and survey of the vessel where the BWM System needs to be installed. The idea is to detect best areas for the installation of the ballast water, reducing the costs and the installation as maximum as possible. For this reason, it is surveyed the different compartments so as to study the different possibilities about the installation during following phases of the process. For a perfect analysis, it is recommended to carry out a 3D scan than can create a perfect image of the compartments (44).

During first phase, it is important to obtain all the information of the vessels such general drawings of the compartments, piping diagrams, power available on board, ballasting operations that will be required…

4.2.2 Phase 2: Feasibility study

One of the most important phases of the project is the feasibility study. It consists on the analysis of all BWMS technologies that are on the market and to all supplier that can provide those technologies. For the analysis, it will be studied not only the technical matters but also the economic field, which we have explained and is a very important factor when deciding which BWM System is more suitable for our vessel.

During the feasibility study, sometime is needed a pilot design to have an idea of the way the technology will needed to be installed and to be easier for the decisions making. In addition, it is usually made a 3D or 2D design (depending on the complexity of the installation) and an onboard survey once the technology has been chosen to ensure that the installation can be implemented without any surprise or any unexpected issue (44).

The normal way to proceed is to start the feasibility study once the vessel survey is carried out and we can have all the information regarding the space, energy consumption, systems that can be affected by the installation… After a proper analysis of the information, it is studied all possible systems as it is essential to choose the most suitable one as it can represent a save of money and consumption for the ship owner and the operator in the long term. Furthermore, it is important to take into account the systems that are already installed on board as the installation of the BWM technology is supposed to interfere the minimum possible to other parts of the vessel. Lastly, but not less important that other factors to be taken into account, it must be ensured that the technology chosen for the vessel meets the standard of the environmental legislation (both international and national depending on the ports that the vessel will call) (40).

4.2.3 Phase 3: Retrofit Engineering

After having analysed the different factors that can affect to our final decision about which technology suits best for our vessel in particular, it is necessary to start the drawings and plans for the installation and the procurements for the approval of the different administrations. The drawings must show the different pipelines, the materials (42)…

In addition, the retrofit engineering needs to take into account different issues regarding (44):

- Class approval: the classification society will require all the documentation of the technology and its installations prior to the approval of class. The installation can start once it is received the approval from the classification society.
- Fabrication: all fabrication of the structure, pipework and electrical parameters need to be taken into account.
- Installation: there needs to be a stated plan for the installation of the technology.

4.2.4 Phase 4: Pre-fabrication

After having made the proper planning and drawing of the installation and the materials that will be used for the installation of the treatment technology, all the components of the system are manufactured to have them before starting the installation of the system.

The different components to be manufactured are the pipework, the structure, the electrical components, the BWMS and all associated equipment (alarms, screens for the control of the system…). For the manufacturing of the components, it is required to know the specifications and materials that will be used in advance to optimize the efficiency of the system.

4.2.5 Phase 5: Installation

The installation can be carried out during sailing, at a shipyard (dry dock) or it can be carried out during sailing and shipyard (combined). In the first case, the installation takes longer (about 6 weeks) compared to the installation in a dry dock (usually about 2 weeks is enough).

Therefore, the installation of a treatment technology is usually carried out in a dry docking as it can represent a saving of time, and collaterally a saving of money for the ship owner. For this reason, it is very important to have a clear plan for the installation to do it correctly the first time that it is installed and to avoid idleness of the project.

The idea is to detect possible problems in advance to reduce as maximum as possible the time of installation and to have the vessel sailing again as soon as possible. For this purpose, it is made a scheduled dry docking that consists of all detailed plan of the timings of installation and the identification of possible handicaps that can be encountered (42).

4.2.6 Phase 6: Verification of the system

Once all the process of installation of the BWM System has been completed, it is necessary to verify that all the system and the different components works as expected. The test is carried out in the shipyard (if it has been installed in dry dock) and it consists on running the system to detect possible risks or problems. The test must be performed with the witness of the shipowner of the vessel (or a representative of him) and the class surveyor.

After the test has been carried out and all the system is working properly, class surveyor can deliver all documentation that prove that the system is complying all international regulations. A recognized classification society (in general in representation of the Flag State) then can receive all the documentation regarding the treatment technology that have been installed and can give final approval for the system. Obviously, the system need to meet the standards not only of the International Maritime Organization but also the national and local water regulations (of the Flag State) (42).

To have a final overview of the process, Figure 19 shows clearly the different phases required to minimize the time of off hire for the installation for a BWMS in an existing vessel:

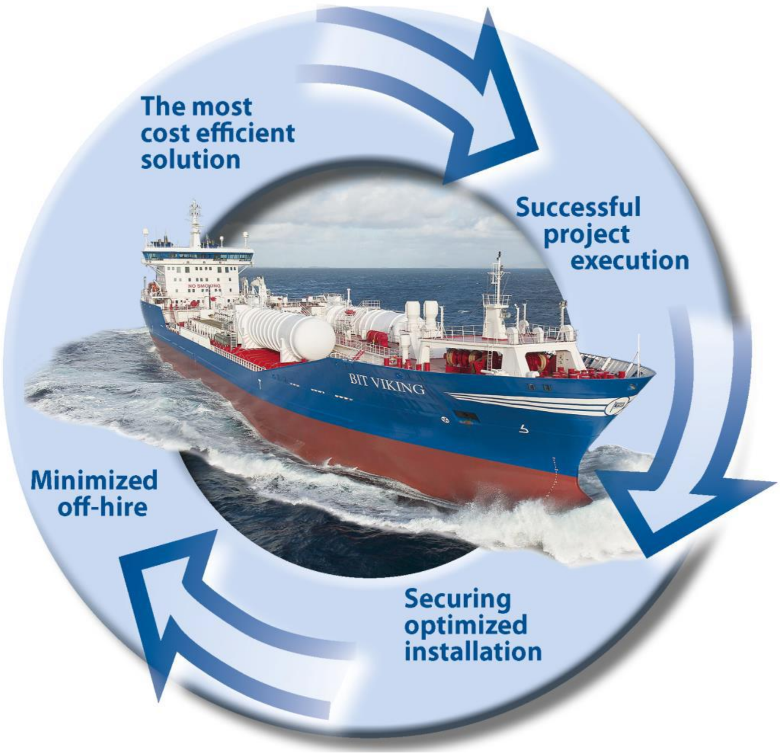


Figure 19. Retrofit Process of BWM system. - Source: ENGINEERING, Elomatic Consulting. GUIDE TO BALLAST WATER MANAGEMENT RETROFITS

Chapter 5. Comparative analysis of different BWM Systems

5.1 Most used systems for Ballast Water treatment

According to DNV GL the most used systems for the treatment of Ballast Water are the following (24):

5.1.1 UV Systems

It is considered that approximately 50 per cent of the vessels required to have a ballast water management system use UV Systems. Usually it is applied first a process of filtration (physical separation), followed by the irradiation of ultraviolet to sterilize the ballast water.

Fundamental reason of the percentage of use in the worldwide fleet is that this system is appropriate for any vessel, despite mainly it is used for vessels that do not require high quantities of ballast water (about 1,000 cubic metres per hour of flow rates). The system is used in many different types of vessels such container vessels, car carriers, general cargo, small bulk or chemical carriers, ferries…

Main benefits for using this combination of filtration and UV treatment method is that it is easy to install and maintain, working without problems in different levels of salinity and water temperatures. In addition, as commented on Chapter 3, it is considered an eco-friendly method for the ballast water treatment (45).

Main inconvenience is that UV treatment has a lower efficiency in turbid water as the rays cannot interfere efficiently into the organisms. For improving the efficiency in case of turbid water, it will require more time to optimize the effect on the organisms.

In Figure 20, it is represented the process of UV Systems:

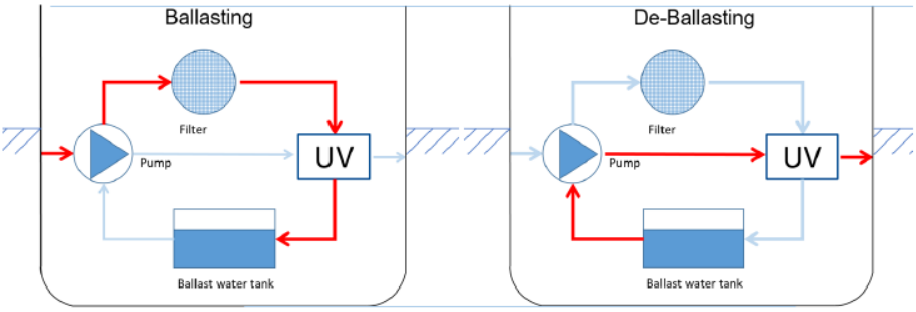


Figure 20. Process of UV Systems. - Source: ENGINEERING, Elomatic Consulting. GUIDE TO BALLAST WATER MANAGEMENT RETROFITS

5.1.2 Electrolytic Systems

It is considered that approximately 35 per cent of the vessels required to have a ballast water management system use electrolytic systems, being the second most used system in terms of total fleet. As in previous case, first step is to carry out a process of filtration (physical separation), followed by the electrolytic treatment.

Electrolytic systems are mainly used in larger ships that need high volumes of ballast water in order to have a perfect control on stability (such bulk carriers). The system is principally thought for vessels that have flow rates about 8,000 cubic metres per hour.

Main benefits for using electrolytic systems are the high efficiency for the treatment of high volumes of ballast water and that the process is carried out inside the tanks. This can represent a benefit for the vessels as it is not required any extra space for the treatment of the ballast water.

Main inconveniences of Electrolytic systems is that they generate an electrolytic reaction, realising very small volumes of hydrogen gas that needs to be taken into account for safety reasons. Furthermore, the efficiency decreases in low levels of salinity and low temperatures of the ballast water. The installation, control and maintenance are much complex compared to UV Systems.

In Figure 21, it is represented the process of Electrolytic Systems:

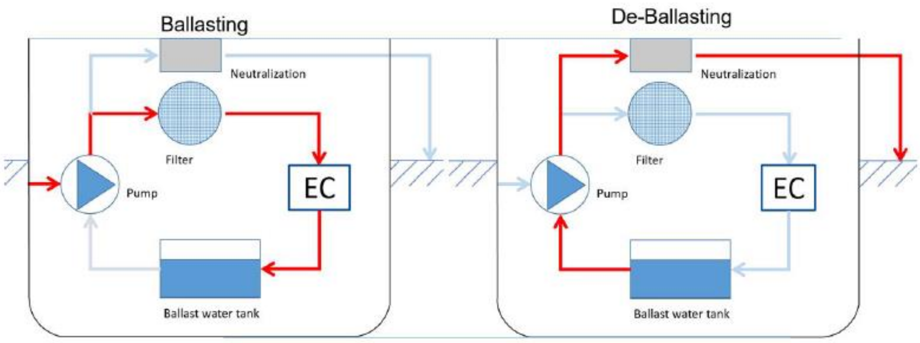


Figure 21. Process of Electrolytic Systems - Source: ENGINEERING, Elomatic Consulting. GUIDE TO BALLAST WATER MANAGEMENT RETROFITS

5.1.3 Chemical Injection Systems

It is considered that only a small percentage of the world fleet uses these systems for the treatment of ballast water. As in other systems, ballast water is first filtrated (separation method), and afterwards, the chemical solution is injected to the water (usually it is liquid or granular). For the chemical solution it is usually used sodium hypochlorite, peracetic acid or chlorine dioxide.

These types of systems are mainly used in larger vessels that can have a flow rate of ballast water of more than 16,000 cubic metres per hour (as chemical tankers and bulk carriers). Moreover, these systems are used for tanks that have loaded or discharged ballast water in local waters without any treatment.

Main benefits for using Chemical Injection Systems are that it is not needed high power consumption (as the energy used for the injection is insignificant), it requires less space than other systems and it is easier to install it.

Main inconveniences of these systems are that chemicals used for the process can only be supplied in specific ports (as chemicals are trademarked), chemicals need to be stored on board in closed containers (considered as hazardous) and the crew must be trained strictly for safety reasons. In addition, it is needed to be supplied regularly of chemicals, increasing the costs comparing to other systems.

5.1.4 Summary of different BWMS

In Table 3, it is you can find a comparison summary of the most used Ballast Water treatment methods:

MAIN FEATURES	UV SYSTEMS	ELECTROLYTIC SYSTEMS	CHEMICAL INJECTION SYSTEMS
TYPE OF VESSELS USING THE METHOD	All types of not very large vessels.	Large vessels (mainly chemical tankers and bulk carriers).	Very large vessels (chemical tankers and bulk carriers).
BW FLOW RATE	Up to 1,000 cbm/h.	Up to 8,000 cbm/h.	Up to 16,000 cbm/h.
PERCENTAGE OF FLEET USING THE METHOD	50 per cent of world fleet using BW treatment methods.	35 per cent of world fleet using BW treatment methods.	Small percentage of world fleet using BW treatment methods.
INSTALLATION & MAINTENANCE	Easy to install & maintain.	Much complex compared to UV Systems.	Easy to install & maintain.
SPACE	Not big extra space needed.	Very small extra space needed.	Very small extra space needed.
MAIN ADVANTAGE	Efficient in different levels of salinity and temperatures.	Method inside ballast water tanks = reduction of space needed.	It requires low power consumption = reduction of space needed.
MAIN DISADVANTAGE	Low efficiency in turbid water.	Low efficiency in low levels of salinity or temperature.	Chemicals to be supplied regularly to be stored on board.

Table 3. Comparison summary of most used BWM Systems. - Source: author.

In Figure 22, we can see the percentage of different types of BW management systems installs by the Scottish company Clean Ship Solutions. They are in charge of studying, installing and maintaining the fleet of different important ship owners like Maersk Tankers, P&O ferries or Northern Marine ferries. As we can observe, the percentage of vessels using UV Systems, Electrolytic systems and Chemical Injection systems are very similar to the percentages explained during this chapter:

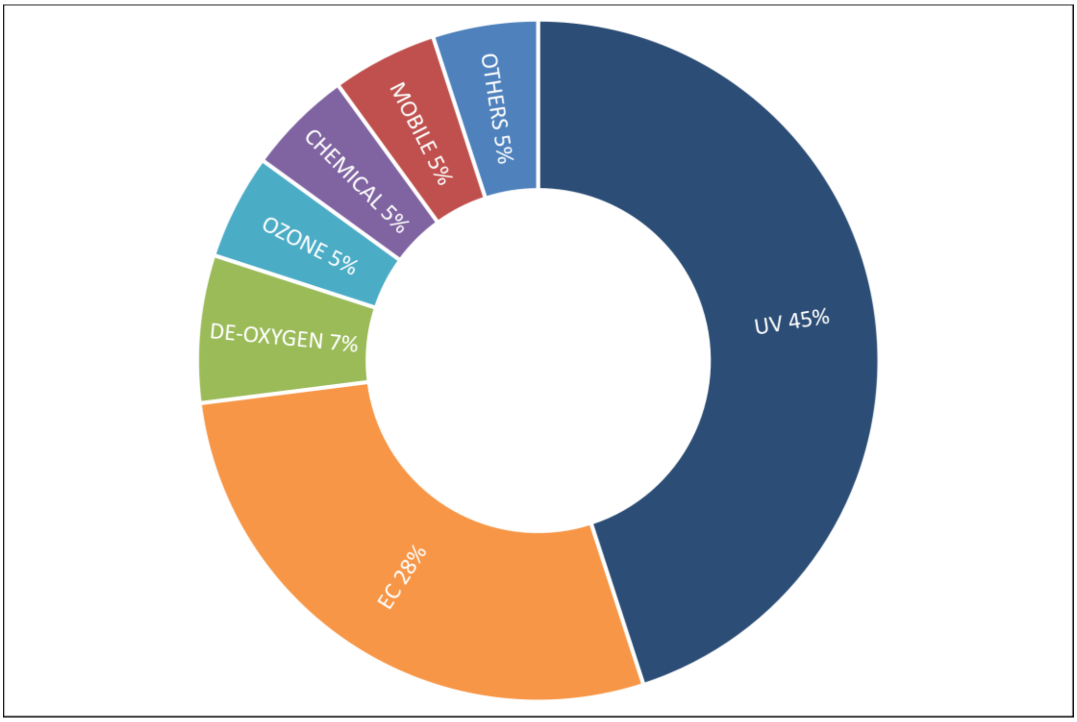


Figure 22. Percentage of BWM Systems used on worldwide fleet. - Source: remake made by author from https://www.cleanshipsolutions.com/ballast-water-management/

5.2 Wärtsilä AQUARIUS® UV ballast water management system (46)

Wärtsilä AQUARIUS® UV ballast water management System is a BW management system approved by the Netherlands (The Ministry of Infrastructure and the Environment). The system has been manufactured by the Finnish company Wärtsilä Water Systems and they got the approval for the system the 20th of December 2012, as per certificate in Figure 23 (MEPC 65/INF.11):

The Netherlands

TYPE APPROVAL CERTIFICATE OF BALLAST WATER MANAGEMENT SYSTEM

This is to certify that the ballast water management system listed below has been examined and tested in accordance with the requirements of the specifications contained in the Guidelines contained in IMO resolution MEPC.174(58). This certificate is valid only for the ballast water management system referred to below.

This certificate is issued to:

Producer	**Wartsila Water Systems Ltd**
Address	Fleets Corner, Poole Dorset BH17 0JT England
Ballast water management system supplied by	**Wartsila Water Systems Ltd**
Under type and model designation and incorporating:	Aquarius UV ballast water management systems using mechanical filtration and ultraviolet radiation models AQ-50-UV to AQ-1000-UV
Ballast water management system manufactured by	**Wartsila Water Systems Ltd**
to equipment/assembly drawing	Single system P&ID; UV-T-001;Issue 3 **Date:** 21.05.2012 Multiple system P&ID; UV-T-002; Issue 3 **Date:** 21.05.2012 Typical P&ID Symbols; UV-T-003 1 **Date:** 29.05.2012
Other equipment manufactured by	See attachment
to equipment/assembly drawing No.	See attachment
Treatment rated capacity	50 to 1000 m3/h Capacities up to 6000 m3/h achieved by using multiple units installed in parallel

A copy of this Type Approval Certificate, should be carried on board a vessel fitted with this ballast water management system at all times. A reference to the test protocol and a copy of the test results should be available for inspection on board the vessel.

Issued at Rotterdam, **December 20 2012**, under no. **11288/2012** .

This certificate remains valid, provided no alternations or modifications are made, until **December 20, 2017**

THE MINISTER OF INFRASTRUCTURE AND THE ENVIRONMENT,
On behalf
THE UNIT MANAGER MARITIME SHIPPING PERMITS,
on behalf,

M.C. Vink
Senior Inspector

Enc. Ratings, Components and Copy of the original test results

Type Approval Certificate of Ballast Water Management System No. 11288/2012 The Netherlands

Figure 23. Approval certificate of Wärtsilä AQUARIUS® UV by the Netherlands. - Source: https://www.wartsila.com/products/marine-oil-gas/ballast-water/bwms/wartsila-aquarius-uv-bwms

The approved system can be installed on board with some variations depending on the size of the vessels or their needs. The capacity range offered can vary from 5-50 cubic metres per hour of flow rate for the less powerful system until 100-1,000 cubic metres per hour for the most powerful system. Moreover, the weight can vary from about 585kg to 2,450kg depending on the flow rate needed.

The system carries out the treatment of the ballast water following two steps:

- Filtration of the ballast water through a back-washing filter.
- Filtered ballast water passes through UV chamber in order to kill microorganisms before entering into ballast water tanks.

Apart from the two different stages, ballast water passes for a second time through UV chamber to maximize the efficiency and minimize any risk.

In Figure 24, it is shown the ballast water management system with the UV chamber in the middle of the system. The idea is that the ballast water passes through the pipe and once it arrives to the UV chamber the lamps radiate ultra violet rays to destroy the microorganisms.

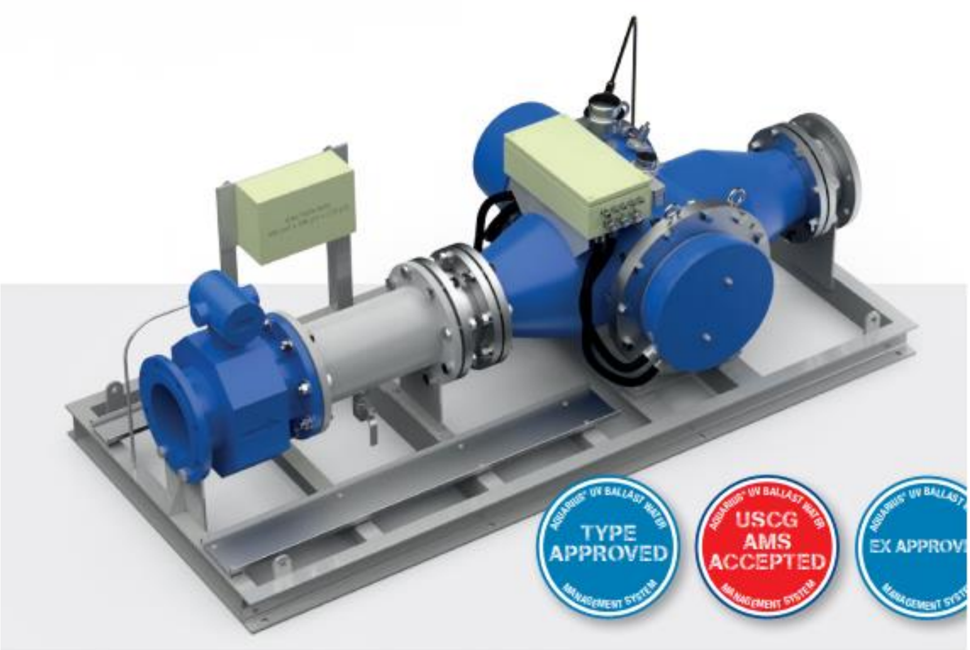


Figure 24. Representation of Wärtsilä AQUARIUS® UV BWMS. - Source: https://www.wartsila.com/docs/default-source/product-files/bwms-files/brochure-o-aquarius-uv.pdf

In Figure 25, it is shown how ballast water passes through the UV chamber and it takes place the radiation of ultra violet rays. To avoid that any particle is obstructed between the different lamps, an automatic wiper removes the particles that can be remaining on them, assuring that the process can be carried out with maximum performance. It is important to remark that the UV chamber is built with stainless steel to avoid any type of corrosion due to salinity of the sea water.

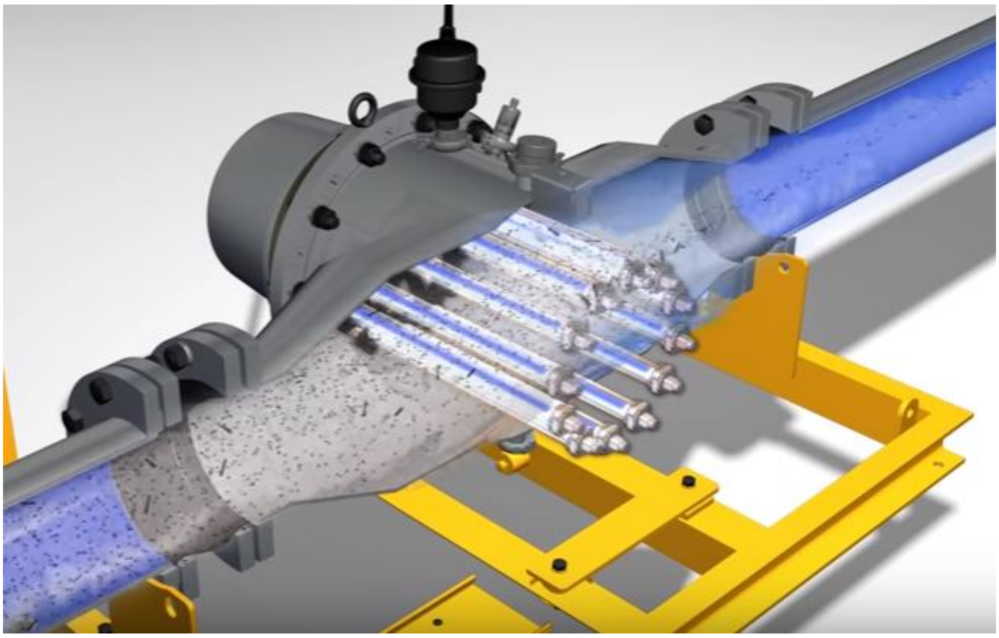


Figure 25. Process of radiation in the UV chamber of Wärtsilä AQUARIUS® UV BWMS. - Source: https://www.youtube.com/watch?v=oSjUYU3uuJA

As this treatment system does not use any type of chemicals, it is considered an eco-friendly method, not being any threat neither for the environment nor for the human health. Moreover, it is easy to install and maintain.

As previously commented in this chapter, main disadvantage is that the efficiency decreases considerably when working with turbid waters due to the difficulty of the UV rays to penetrate the organisms.

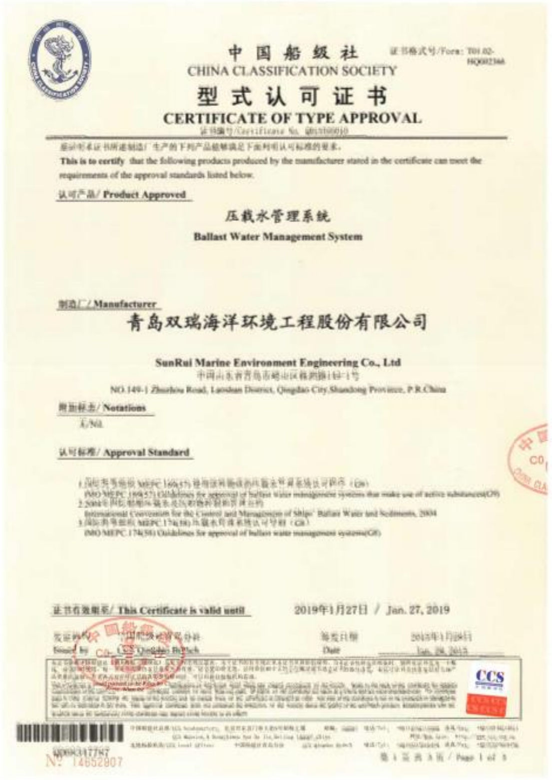
Wärtsilä AQUARIUS® UV ballast water management system has following specifications (47):

- Approvals: IMO (G8), USCG AMS
- UV: Cross Flow, Medium Pressure
- Filter: Filtersafe (Screen)
- Self Backflushing?: Yes
- Active Substances: No
- Max Power (kW/100m^3/hr): 10-20
- Typical Pressure Drop (bar): 0.2-0.4
- Capacity (m^3/hr): 0-100, 100-250, 250-500, 500-750, 750-1000.

For a better understanding of how the system works, following video illustrates perfectly the process carried out in Wärtsilä AQUARIUS® UV ballast water management system: https://www.youtube.com/watch?v=oSjUYU3uuJA

5.3 BalClor Ballast Water Management System

BalClor Ballast Water Management System was manufactured by the Chinese company Qingdao Sunrui Corrosion and Fouling Control Company and was approved by IMO the 1st of November 2010 (MEPC 61) (48):



中国船级社
CHINA CLASSIFICATION SOCIETY
型式认可证书
CERTIFICATE OF TYPE APPROVAL

This is to certify that the following products produced by the manufacturer stated in the certificate can meet the requirements of the approval standards listed below.

认可产品/ Product Approved

压载水管理系统
Ballast Water Management System

制造厂/ Manufacturer

青岛双瑞海洋环境工程股份有限公司

SunRui Marine Environment Engineering Co., Ltd

NO.149-1 Zhuzhou Road, Laoshan District, Qingdao City, Shandong Province, P.R.China

附加标志/ Notations

无/Nil

认可标准/ Approval Standard

International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004

IMO MEPC.174(58) Guidelines for approval of ballast water management systems(G8)

证书有效期至/ This Certificate is valid until 2019年1月27日 / Jan. 27, 2019

Issued by CCS Qingdao Branch

Page 1 of 1

Figure 26. Approval certificate of BalClor by China Classification Society. – Source: http://www.sunrui.net/images/content/2016/20161220165931249797.jpg

SunRui technology offers a wide range of flow rates that works from 500 cubic metres per hour up to 6,000 cubic metres per hour. For this reason, the system was installed in 328 vessels of different types until April of 2016 (mainly Asiatic clients like NYK Line, MOL or China Shipping Tanker) (49). In Figure 27, it shows the number of systems installed until the date mentioned:

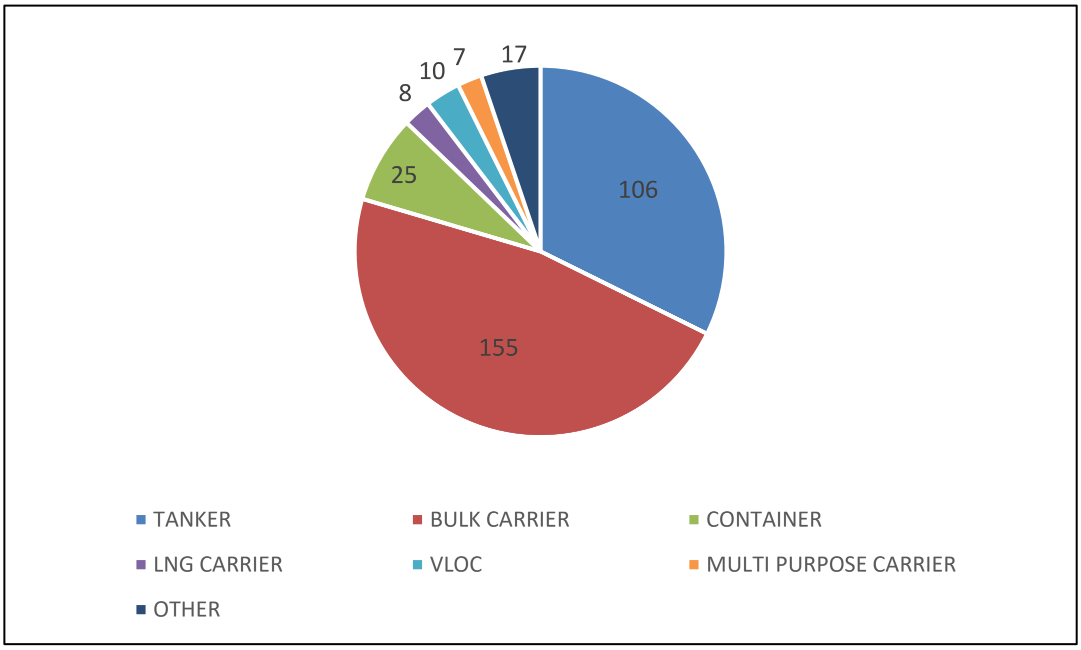


Figure 27. Number of BalClor systems installed in the different type of vessels. - Source: author. Data extracted from: http://conference9.diorama.gr/images/presentations/Vincenti_Li.pdf

For the treatment of the ballast water, the system uses following steps (50):

- Filtration of the ballast water: The system filtrates the water while ballasting, not letting the organisms bigger than 50um enter into the tanks and discharging them back to local water.
- Electro-chlorination: the ballast water that enters into the tanks is guided to the electrolysis unit. Once located in the unit, a specific concentration of Sodium Hypochlorite solution is injected to be mixed with sea water, being capable of destroying marine organisms that remain on the ballast tanks that have not been possible to filtrate due to their size.
- Neutralization: when carrying out the de-ballasting of the vessel, the monitoring system assures the concentration of the Sodium Hypochlorite solution is lower than the maximum permitted by the IMO requirement. In case of having a higher concentration than the one permitted, the neutralization unit realizes a neutralization agent to reduce the concentration of the solution.

For the control of the active agents in main pipeline, it is used a TRO unit (Total Residual Oxidants) which is a sensor that sends information to main control unit. In Figure 28, it shows the process the ballast water follows on the system during both the ballasting and the de-ballasting, being controlled the level of concentration thanks to the TRO unit:

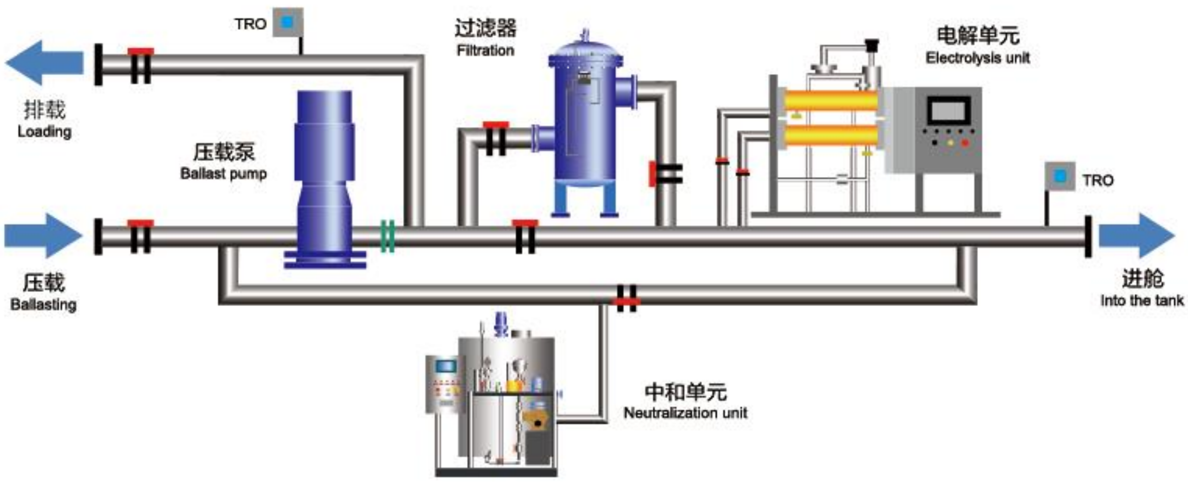


Figure 28. Treatment process of the BW in BalClor BWMS. - Source: http://www.sunrui.net/images/content/2016/20161220165513450127.jpg

In Figure 29, you can find a real installed BalClor Ballast Water Management System in a 110k DWT Crude Oil Tanker for the shipyard Dalian Shipbuilding Industry Co., Ltd:

Figure 29. 110,000DWT Crude Oil Tanker where Balclor was installed. – Source: http://www.sunrui.net/SOLUTION/bwm/320270.htm

The specifications are following (50):

- Country of Origin: China
- Approvals: IMO (G9), USCG AMS
- Certificates: ABS, BV, CCS, DNV, LR, NK
- Active Substances: Yes
- EC: Sidestream
- Filter: Proprietary
- Self Backflushing?: Yes
- Max Power (kW/100m^3/hr): 10-20
- Typical Pressure Drop (bar): 0.4-0.6
- EX Option: Yes
- Capacity (m^3/hr): 500-750, 750-1000, 1000-1250, 1250-1500, 1500-2000, 2000-2500, 2500-3000, 3000+

For a better understanding of how the system works, following video illustrates perfectly the process carried out in BalClor Ballast Water Management System: https://www.youtube.com/watch?v=EdLcKnZBy-Q

5.4 JFE BallastAce that makes use of NeoChlor Marine® Ballast Water Management System

JFE BallastAce system was manufactured by the Japanese company JFE Engineering Corporation and was approved by IMO the 15th of July 2011 (MEPC 62) (48):

TYPE APPROVAL CERTIFICATE OF BALLAST WATER MANAGEMENT SYSTEM

JAPAN

Figure 30. Approval certificate of JFE BallastAce by The Japanese Government. – Source: https://jfe-ballast-ace.com/wp/wp-content/themes/jfe/img/product_18.png

The system can work with a flow rate from 500 cubic metres per hours up to more than 3,000 metres per hour depending on the needs of the vessel where it is installed. As previously commented about chemical injection systems, main disadvantage for JFE BallastAce is that it is required to have regular supplies of the chemical used (in this case NeoChlor Marine) as they need to be stored on board for the daily use. Furthermore, the crew need specific training for the use of the chemical and the system so as to reduce the probability of accident.

About the benefits, it is clearly a perfect system for minimizing the consumption of the ballast water system, it reduces the chance of mechanical failure (easy to operate and maintain) and it does not require a big space for the system (51).

For the treatment of the ballast water, the system uses following steps:

- Filtration of the ballast water: The system filtrates the water while ballasting, avoiding the entrance of the biggest particle/organisms, minimizing the risks of entrance of invasive species.
- Chemical Injection: once the biggest particles have been filtered and the system has avoided the entrance into the ballast tanks, the disinfectant injector introduces into the flow the NeoChlor Marine. Thanks to the chemical solution, the particles and organisms are killed before ballast water enters into the tanks to optimize the stability of the vessel.
- Neutralization: when carrying out the de-ballasting of the vessel, the monitoring system assures the concentration of NeoChlor Marine is not dangerous for the environment and assures the level of microorganisms does not exceed the levels permitted according to IMO standards. If the level of concentration is too high, it is applied the neutralizer (TG Environmentalguard, a mixture of Sodium sulphite Na_2SO_3) to ensure a safe concentration of the chemical used.

In Figure 31 and Figure 32, it is represented all the process for both ballasting and de-ballasting:

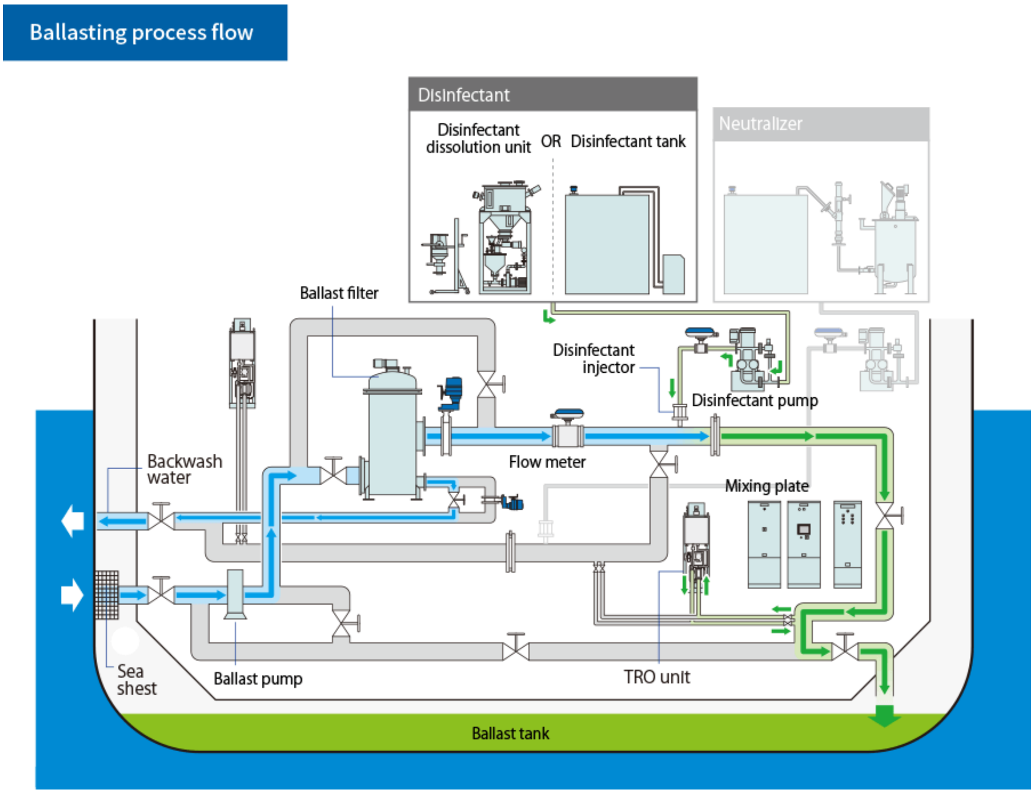


Figure 31. Ballasting process of JFE BallastAce BWMS. - Source: https://jfe-ballast-ace.com/wp/wp-content/themes/jfe/img/product_05_lg_en.png

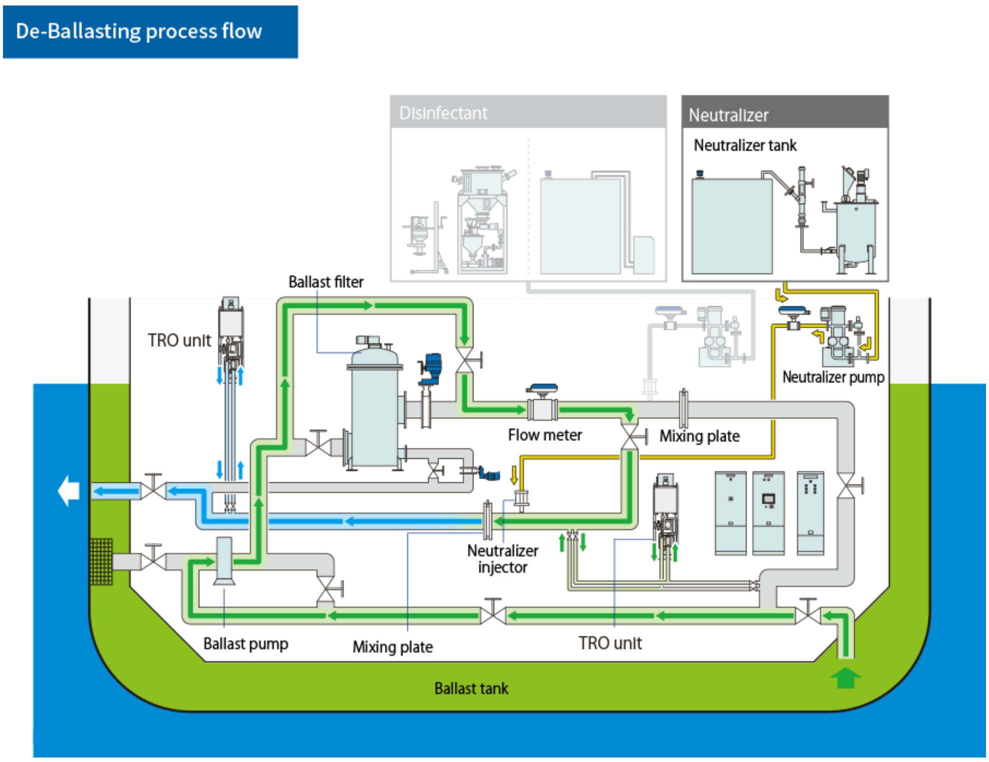


Figure 32. De-ballasting process of JFE BallastAce BWMS. - Source: https://jfe-ballast-ace.com/wp/wp-content/themes/jfe/img/product_06_lg_en.png

The chemical used is NeoChlor Marine which is a granular substance that consists on a mixture of sodium dichloroisocyanurate dihydrate (NaCyCl2) that need to be stored in a dry room below 40ºC (it is considered a IMDG substance). This type of substance is recommended mostly for tramper vessels or vessels that have short time to receive supplies before operations commencement (1 hour for example) such LNG Carriers. The chemical is usually supplied as any other supply received by the vessel (using the service crane of the vessel), as shown in Figure 33:

Figure 33. Supply of NeoChlor Marine process. – Supply: https://jfe-ballast-ace.com/wp/wp-content/themes/jfe/img/operation_08.png

Main difference to other systems that we have already explained, is that in this type of system it is required the collaboration of the crew for a proper use of the system. The crew need to be in charge of the addition of the chemical substance and while de-ballasting of the neutralizer (52).

In Figure 34, it is represented how the crew need to proceed for adding the chemical substance into the system :

1. The container of NeoChlor Marine is placed in the Disinfectant Transfer Unit and once it is fixed, the container is vertically spun.
2. The transfer unit is placed in correct position.
3. The container is lowered and connected to the pipe. In this step the container is emptied.
4. The granular solution is dissolved with fresh water to the concentration level required, making the final disinfection solution which afterwards will be mixed with the ballast water.

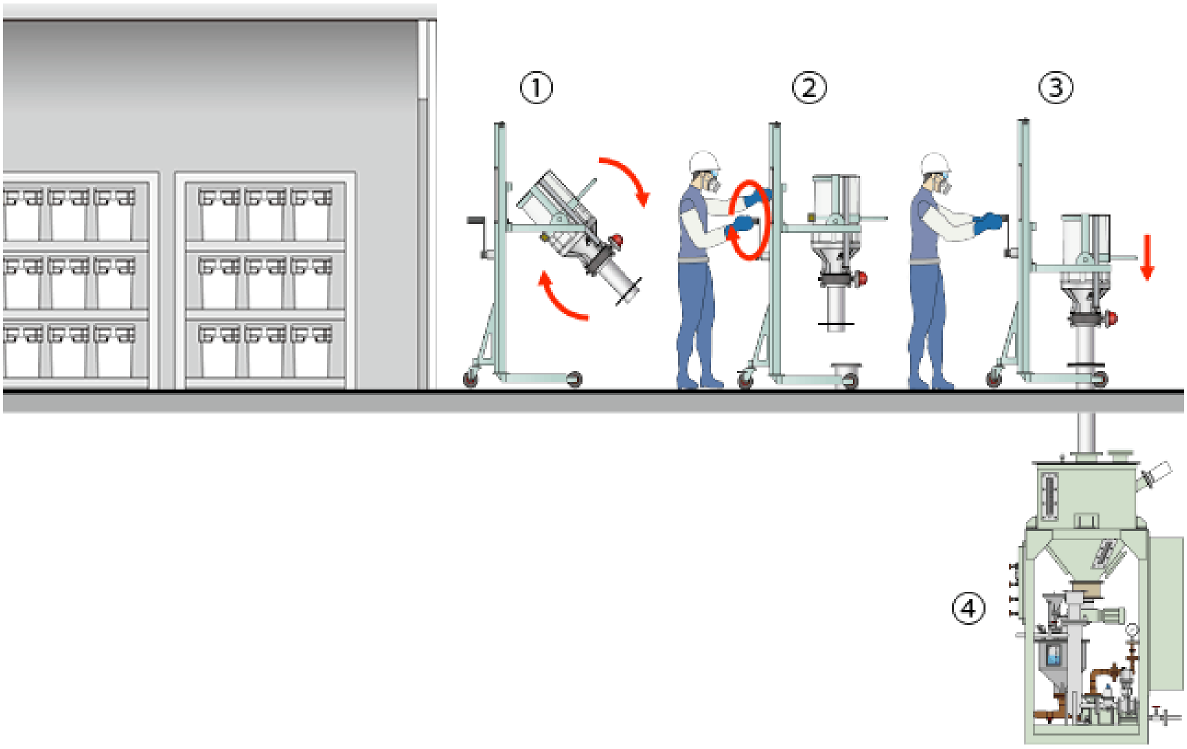


Figure 34. Process for adding NeoChlor Marine into JFE BallastAce BWMS. – Source: https://jfe-ballast-ace.com/wp/wp-content/themes/jfe/img/operation_11.png

Finally, in Table 4 we can see the number of vessels and the types that have installed JFE BallastAce system for the treatment of their ballast water. As we can observe, most of vessels are new build ships and in particular, bulk carriers (338 new building bulk carriers in total). About the sizes of bulk carriers, most of new building bulk carriers are Handymax[2] (126 vessels) and Panamax[3] (126 vessels), followed by Cape Size[4] (64 vessels) (53). Therefore, we can conclude that JFE BallastAce Ballast Water Management System is mainly used in bulk carrier of big sizes.

[2] Vessels of 40,000 – 50,000 Dead Weight Tonnage (DWT).
[3] Vessels of 52,000 – 80,000 DWT. This is the largest size of vessel that can traverse the original Panama Canal.
[4] Vessels of more than 150,000 DWT. These type of vessels cannot traverse the upgraded Panama Canal due to their size.

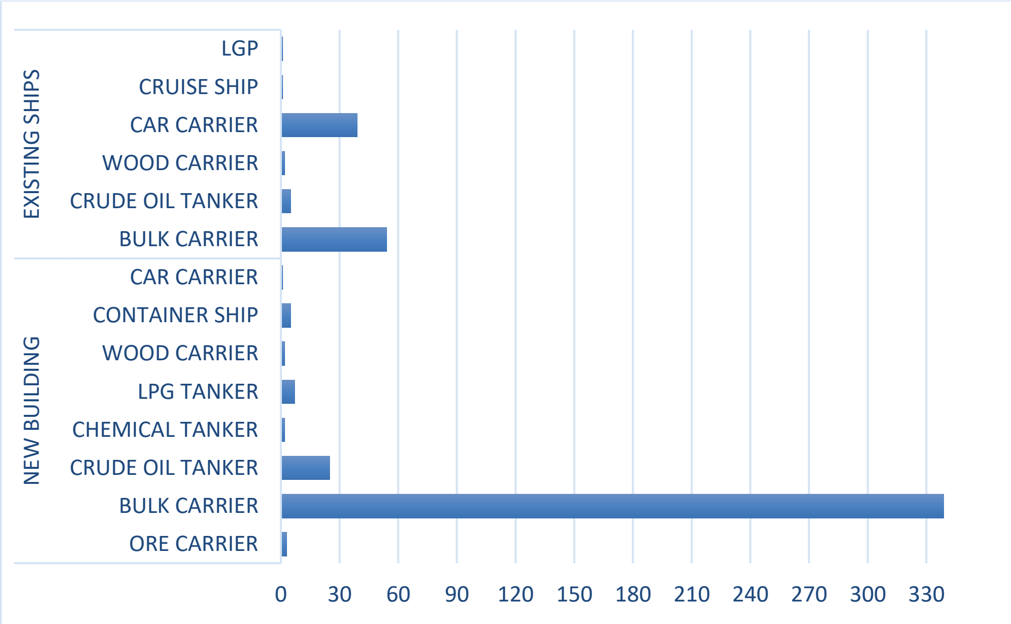


Table 4. Number of JFE BallastAce installed on board by type of vessels. - Source: author. Data extracted from: https://jfe-ballast-ace.com/product/#cbox01

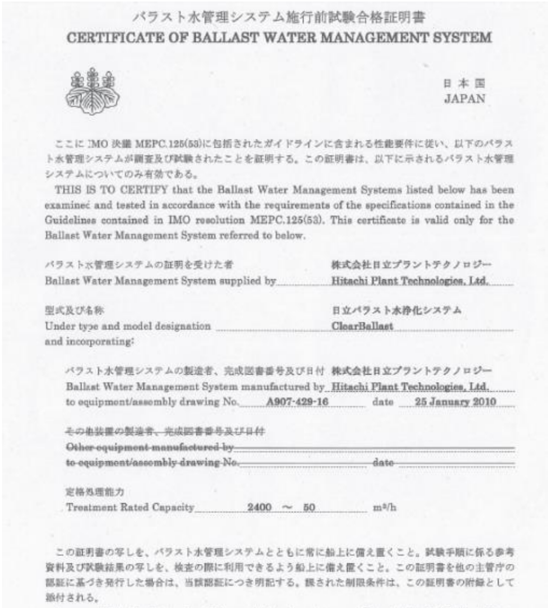
The specifications are following (54):

- Country of Origin: Japan
- Approvals: IMO (G9), USCG AMS
- Active Substances: Yes
- Filter: Proprietary
- Self Backflushing?: Yes
- Max Power (kW/100m^3/hr): 0-10
- Typical Pressure Drop (bar): 0.4-0.6
- EX Option: No
- Capacity (m^3/hr): 500-750, 750-1000, 1000-1250, 1250-1500, 1500-2000, 2000-2500, 2500-3000, 3000+

For a better understanding of how the system works, following video illustrates perfectly the process carried out in JFE BallastAce Water Management System: https://www.youtube.com/watch?v=Hmmedc3dPBQ

5.5 Hitachi Ballast Water Purification System (ClearBallast)

Hitachi Ballast Water Purification System (ClearBallast) is a BW management system was manufactured by the Japanese company Hitachi, Ltd./Hitachi Plant technologies, Ltd and approved by IMO the 4th of April 2008 (MEPC 57) (48):



パラスト水管理システム施行前試験合格証明書
CERTIFICATE OF BALLAST WATER MANAGEMENT SYSTEM

日本国
JAPAN

ここに IMO 決議 MEPC.125(53)に包括されたガイドラインに含まれる性能要件に従い、以下のバラスト水管理システムが調査及び試験されたことを証明する。この証明書は、以下に示されるバラスト水管理システムについてのみ有効である。

THIS IS TO CERTIFY that the Ballast Water Management Systems listed below has been examined and tested in accordance with the requirements of the specifications contained in the Guidelines contained in IMO resolution MEPC.125(53). This certificate is valid only for the Ballast Water Management System referred to below.

バラスト水管理システムの証明を受けた者 株式会社日立プラントテクノロジー
Ballast Water Management System supplied by Hitachi Plant Technologies, Ltd.

型式及び名称 日立バラスト水浄化システム
Under type and model designation ClearBallast
and incorporating:

バラスト水管理システムの製造者、完成図書番号及び日付 株式会社日立プラントテクノロジー
Ballast Water Management System manufactured by Hitachi Plant Technologies, Ltd.
to equipment/assembly drawing No. A907-429-16 date 25 January 2010

~~その他装置の製造者、完成図書番号及び日付~~
~~Other equipment manufactured by~~
~~to equipment/assembly drawing No.~~ ~~date~~

定格処理能力
Treatment Rated Capacity 2400 ～ 50 m³/h

この証明書の写しを、バラスト水管理システムとともに常に船上に備え置くこと。試験手順に係る参考資料及び試験結果の写しを、検査の際に利用できるよう船上に備え置くこと。この証明書を他の主管庁の認証に基づき発行した場合は、当該認証につき明記する。課された制限条件は、この証明書の附録として添付される。

Figure 35. Approval certificate of Hitachi Ballast Water Purification System by The Japanese Government. – Source: https://www.jstage.jst.go.jp/article/jime/46/4/46_561/_pdf/-char/en

It exists different sizes of system depending on the size of the vessel where the system needs to be installed and her needs. The capacity can vary from 200 cubic metres per hour of flow rate up to 2,400 cubic metres per our when it is required to treat high volumes of ballast water. In this way, the power consumption of the system is proportional to the capacity needed to treat. In this case, the estimated power consumption system is 21 kW for 200m^3/h (for the less powerful) and 170 kW for 2,400m^3/h (for the most powerful) (55).

The system carries out the treatment process of the ballast water following four different steps (56):

- Once the ballast water is pumped into the system, it is added the magnetic power and flocculation agents. After the water has been inside the coagulation tank and flocculation tank, the organisms become magnetized flocs of around 1mm.
- The magnetized flocs pass through the magnetic separator, where thanks to the magnetic disc the organisms are separated from the ballast water.
- The separated flocs (plankton, bacteria…) are killed in the floc tank using a heat treatment.
- Lastly, the water that has been separated from the flocs is passed through a filter separator to minimize the risk of containing organisms of small sizes or that have not been treated correctly during the process. After this step, the water can enter into the ballast tank.

In Figure 36, it is shown all process including from the pumping of the seawater until the introduction of the treated ballast water into the ballast tank of the vessel:

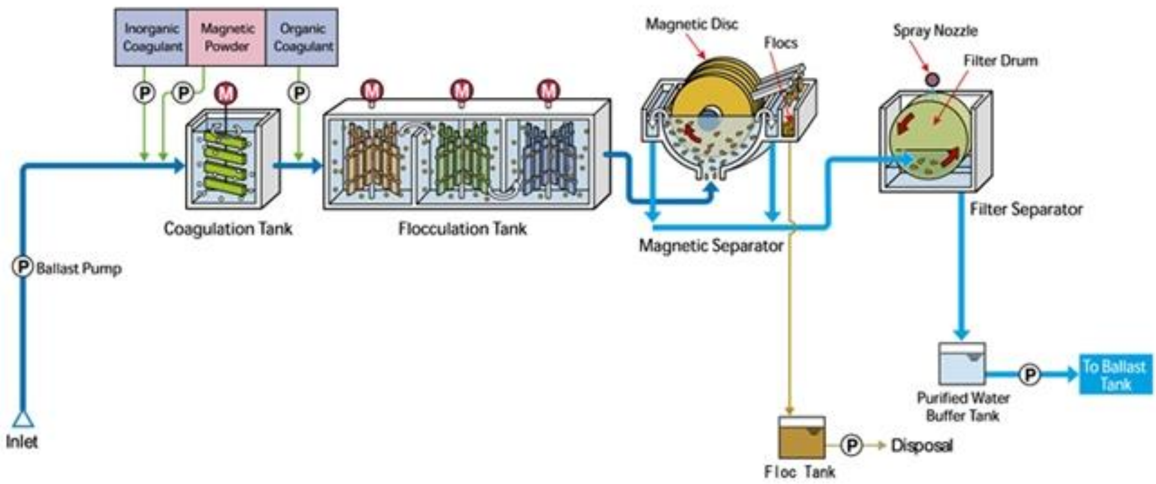


Figure 36. BW treatment process of ClearBallast. - Source: https://www.mhi.com/news/story/100315en.html

Main advantages of the use of Clear Ballast treatment technology are that there is no need of using any type of chemicals that can represent a threat for the environment, it can remove other types of residues from the system (like the sand of the seawater), it is usually not needed an extra generator as the power consumption is not very big and it cannot represent any problem for the walls or coatings from inside ballast tank as no chemical is used.

Main disadvantage for Hitachi Ballast Water Purification System is that vessel will need an extra space where the coagulation tank and flocculation tank are placed. In this way, it is not a very good option for those vessels that do not have much space and requires a system that does not need big extra space for its proper functioning. In Figure 37, we can make an idea of how much space is needed on board:

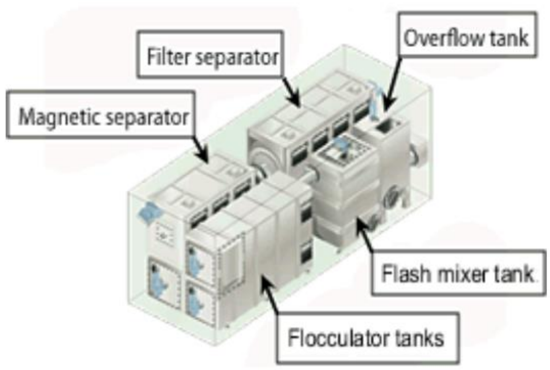


Figure 37. Real ClearBallast installed on board a vessel and its representation. – Source: http://www.csamarenostrum.hr/userfiles/files/istrazivanje_i_razvoj/balmas/radni_paketi/radni_paket_4/4.3/Ballast%20water%20purification%20system(ClearBallast).pdf

Hitachi Ballast Water Purification System (ClearBallast) has following specifications:

- Country of Origin: Japan
- Approvals: IMO (G8)
- Filter: Proprietary
- Self Backflushing?: Yes
- EX Option: No
- Capacity (m^3/hr): 200, 400, 800, 1,200, 1,600, 2,400.

For a better understanding of how the system works, following video illustrates perfectly the process carried out in Hitachi Ballast Water Purification System (ClearBallast): https://www.youtube.com/watch?v=UtB-5KM3tjE

5.6 Brief comparison

In Table 5, we can see a brief comparison and summary of the 4 different BWM systems analysed during our work.

In conclusion, after having analysed the different treatment technologies that appears on the table, we can conclude that there is not an only option when choosing a BWM System. The decision of which BWM System is better for a specific vessel will depend on her size, her purpose and the area where the vessel will be sailing. For this reason, it is very important to make a full analysis of the vessel and her purposes in order to detect which treatment technology can affect more positively to her operational needs.

For example, if the specific vessel needs a huge volume of ballast water as she needs to control efficiently the stability of the vessel, probably best idea would be of installing BalClor BWM System as it has a capacity up to 6,000m^3/h. This would be the case of tanker vessels and bulk carriers.

On the contrary, if the vessel is not very big or due the type of vessel she does not need to manage big volumes of ballast water, Wärtsilä Aquarius UV with a capacity of 100m^3/h can be a good option as it is easy to install and maintain. Another option would be to install ClearBallast of 200m^3/h of capacity with the negative point of needing a big space for the different tanks, being not a good option when the vessel does not have much space on board for placing the system.

MAIN FEATURES	WÄRTSILÄ AQUARIUS® UV	BALCLOR BWM SYSTEM	JFE BALLASTACE	CLEARBALLAST
METHOD USED	Filtration + Ultra Violet	Filtration + Electro Chlorination	Filtration + Chemical Injection	Coagulation + Magnetic treatment + Filtration
DATE OF APPROVAL	20TH December 2012 (MEPC65)	1st November 2010 (MEPC61)	15th July 2011 (MEPC62)	4th April 2008 (MEPC 57)
COUNTRY OF ORIGIN	Finland	China	Japan	Japan
COMPANY	Wärtsilä	Qingdao SunRui CFCC	JFE Engineering Corporation	Hitachi, Ltd
CAPACITY m^3/h (FROM – TO)	100 – 1,000	500 – 6,000	500 – 3,000	200 – 2,400
INSTALLATION & MAINTENANCE	Easy to install and maintain.	Complex to install and maintain.	Easy to install and maintain.	Complex to install and maintain.
MAIN ADVANTAGES	- Efficient in different levels of salinity and temperature. - Eco-friendly (no use of chemicals).	- Not big space needed as the treatment process is carried out inside ballast tanks.	- Minimum power consumption. - Not required big space. - Minimum probability of mechanical failure.	- Eco-friendly (no use of chemicals). - Very low power consumption.
MAIN DISADVANTAGES	- Low efficiency in turbid waters.	- Low efficiency when low levels of temperatures or salinity. - Use of chemicals.	- It requires regular supply of the chemical used. - Crew needs specific training for the use of the chemicals.	- Big space needed for the different tanks.
OTHER COMMENTS	Weight of the system from 585kg up to 2,450kg.	Neutralization process when carrying out de-ballasting.	Neutralization process when carrying out de-ballasting.	It can remove other residues from the system (sand).

Table 5. Comparison summary of the different BWM Systems analysed. - Source: author

Chapter 6. How to reduce Ballast Water impact

6.1 Importance of the control of Ballast Water of ships

As we have seen during all the work, the ballast water control is very important not only for the environment but also for the human health and the economy. International organizations are aware of the problem and they have done the first step by implementing the BWM Convention, which represent a clear progress for the reduction of the impact when using ballast water on ships.

In this way, it exists different projects or studies that are still trying to investigate how the impact of ballast water can be reduced. The idea is to achieve the minimum impact from ships when improving their stability by using other types of systems or improving the efficiency of the ballast water systems.

6.2 GloBallast Partnership

The GEF-UNDP-IMO GloBallast Partnership Programme is trying to assist developing countries to reduce the impact of the ballast water impact by the implementation of the BWM Convention. The idea is to push and assist them to act properly in front of one most important threats when talking about vessel's impact on the world.

The programme was driven in 2000 to 2004 with a pilot program, and in 2007 by three important organizations: the Global Environment Facility (GEF, contributing with the funding of the project), the United Nations Development Programme (UNDP, in charge of the implementation) and the International Maritime Organization (IMO, in charge of the execution). Main idea was to stablish a period of time to implement the measures of BWM Convention to assure that the problem of the ballast water is controlled in all over the world. Initially it was set a period of 5 years (from October 2007 up to October 2012) to implement BWM Convention, but it was finally extended until June 2017, 10 years from the date of start of the project (57).

Despite the first phase of the programme was thought for learning and study of ways of the implementation of BWM Convention, the second phase was leaded by 15 different countries: Argentina, Bahamas, Chile, Colombia, Croatia, Egypt, Ghana, Jamaica, Jordan, Nigeria, Panama, Trinidad and Tobago, Turkey, Venezuela and Yemen (58).

Apart from the main organizations that were driving the project, there were many partners contributing to the Programme like shipping industries, governmental organizations, national administrations… It is important to remark that the project had an initial invest of USD 13.7M from GEF & UNDP and USD 51.9M of co-financing contribution.

During the 10 years of programme it was achieved following figures, with 30 technical publications and more than 100 countries participating on the programme:

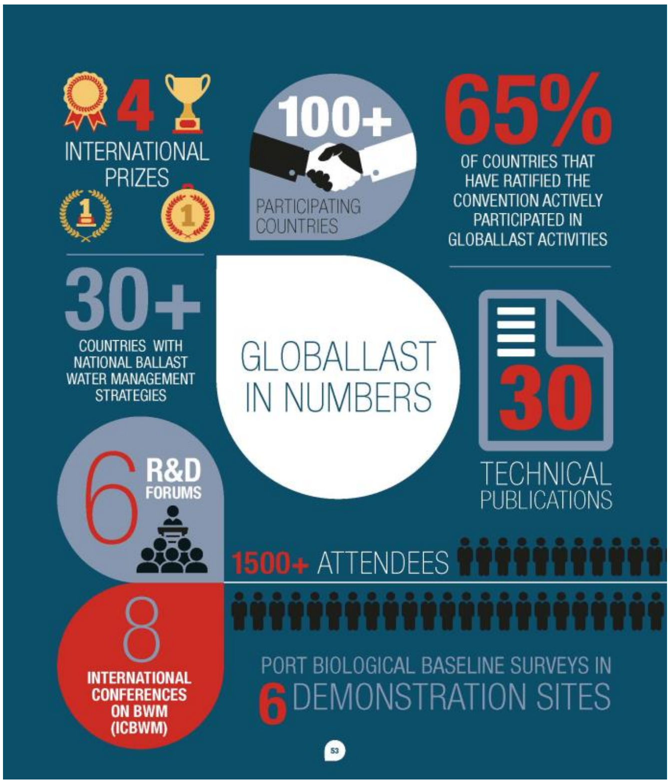


Table 6. Achievements of GloBallast Partnership from 2007 to 2017. – Source: http://www.imo.org/en/OurWork/Environment/MajorProjects/Pages/GloBallast-in-numbers.aspx

Some of most important achievements of the GloBallast Partnership are following:

- The project has established a Project Coordinator Unit at IMO.
- It developed a common network where it can be found many databases, newsletter all other relevant information regarding ballast water from vessels.
- It was developed different model of legislations to be applied about the BWM Convention.
- It has been reviewed the legislation regarding the control of ballast water in different countries and those countries have been help out by the project to implement improvements on the national/local legislation.
- The programme has developed a specialized training for the ballast water treatment, not only for the crew but also for the staff ashore from the companies affected by the BWM Convention.

6.3 Proposals according to Ballast Water Management Infrastructure Investment Guidance

Ballast Water Management Infrastructure Investment Guidance is a document published by IMO published with the idea of providing guidance about where it would be necessary to invest in order to reduce the impact of ballast water. The study was financed by Royal HaskoningDHV and the European Bank for Reconstruction and Development, with the contribution of GloBallast partnership (8).

The document identifies different actors or infrastructures that by means of a big or a small investment, it can represent a big benefit in terms of mitigation of the impact of the ballast water de-ballasted from ships. We can find following measures to be implemented by Governments/International organizations depending on the funds invested:

- Installation of ballast tanks sediments reception and disposal facilities in different ports: despite it seems a very difficult way of minimizing the risk of the ballast water, it can represent a big benefit if the ports install disposal facilities for ballast water. Thanks to this measure, it would be clearly reduced the impact of alien species on local environments. This is considered to be a medium expenditure measure (between 500,000 Euros up to 2M Euros).
- Monitoring system of the biodiversity: by controlling and monitoring the status of the biodiversity, it can be detected the different alien species when they are discharged from a ballast tank and they have started to spread. This is not an expensive measure and it can improve the control and monitoring of local biodiversity.
- Proper regular cleaning of ballast water sediments: despite it is not an expensive measure to be applied on board the vessels, it can have a big effect on the spreading of alien species. In the case of a long sailing time, the regular cleaning of the ballast water contained in the tanks can represent the complete cleaning of the ballast water. This can achieve that it does not remain almost any organism on them when de-ballasting.
- Improvement of Port State Controls regarding ballast water: more control on the BW discharge would be clearly beneficial for avoiding malpractices from the vessels. In this way, ports and local authorities should inspect frequently the record books, carry out sampling of the ballast water or be more strict when getting the initial certificate or the renewal of the Ballast Water Management Plan. The measures can have a big benefit without making a big expense as mainly the increase of cost will be for hiring more people for the control of the vessels. No extra equipment needed.
- Public investment for the study of alternative technologies: as we have seen during this work, it exists many different types of technologies to be used for the treatment of ballast water to comply with the standards of IMO. Anyway, it is necessary the study of alternative technologies for the control of the stability of the vessels without the use of ballast water. If it is found a way for replacing the BWMS, it can clearly contribute to the reduction of pollution from ships. Main problem for this measure, is that it can represent a big expense for the public institutions or the governments.
- Reduction of taxes to vessels using alternative technologies: in relation with last proposal about the investment on alternative technologies, it could be applied a worldwide reduction of the

taxes and tariffs of the different ports for those vessels not using ballast water for the stability. This proposal could help to shipowners to make a final decision of investing in other types of systems in order to achieve an efficient and ecological vessel in terms of the stability without the use of ballast water. The proposal does not need any investment, but it can signify a slight reduction of the benefits of the different ports applying the suggested measure.

6.4 Alternative technologies to Ballast Water

During all the study we have seen how the ballast water affects to the environment and how it can be reduced its impact thanks to the treatment technologies and the standards determined by the International Maritime Organization. As we have already explained, the use of ballast water has become essential for the vessels in order to maintain a safe stability, improve the propulsion and the manoeuvrability, and to reduce the stress hull.

After the International Convention for the Control and Management of Ships' Ballast Water and Sediments was adopted in 2004 and entered into force in 2017, different shipowners and operators have put their effort and investments to comply with the new regulations of the IMO. As we have explained in Chapter 2, the different standards have signified an adaptation of existing ships that has been possible only with a big investment on technologies and installation on board. However, it exists other alternatives to BW in order to improve the stability of the vessels without the need of invest on technologies meeting the standards fixed by the IMO.

The alternative methods for replacing the ballast water would signify that there will be no need for shipowners/operators to meet any standards regarding BW Convention or other related regulations. In addition, the use of alternative methods can signify a clear reduction of the costs concerning the maintenance, the electrical consumption and the no need of using additional pumps, valves or other equipment associated to the BWM System (59).

Different alternatives have been studied by different companies in the last year. The idea is to increase the draft from vessels to avoid a short draft when the vessel is sailing without any cargo, when the risk of bad stability is higher. Some of the alternative are following:

- 25 tonne containers to replace ballast water:
  In this way, the South Korean company Daewoo Shipbuilding & Marine Engineering studied the way of using 25 tonnes containers for improving the stability of their container vessels. The idea is to improve the stability of the vessel by loading these heavy containers on a specific stowage position depending on the needs of the vessel in every circumstance (depending if she is sailing with cargo or without any cargo). The containers would replace the ballast water and there will be no need of installing any special technology on board. Moreover, there will be no need of complying any extra regulation as the vessel will load only containers and it does not exist any type of risk for the environment. Finally, the use of 25 tonnes containers can control not only the draft but also the trim of the vessel.
  Main disadvantage for this method is that it is required to carry always on board some containers for improving the stability or to have the 25 tonnes containers in the different ports that vessel calls.

- Use of variable buoyancy system (60):

  Another alternative was studied by the University of Michigan in order to avoid the use of ballast water on ships. On the study of the University, they proposed to replace the need of the ballast tanks with the use of variable buoyancy systems thanks to different trunks that goes from bow to stern below the waterline. Thanks to this method, the water can pass below the cargo holds and the buoyancy of the vessel can clearly be reduced. Thanks to this method, there is no need of increasing the weight of the vessel and the water that pass through the trunks cannot represent any danger as it is not stored on the tanks of the vessel (and released immediately).

  Main disadvantage for this alternative method is that the ballast-free hull designs represent a higher cost of building and a higher operational cost due to the wear of the hull.

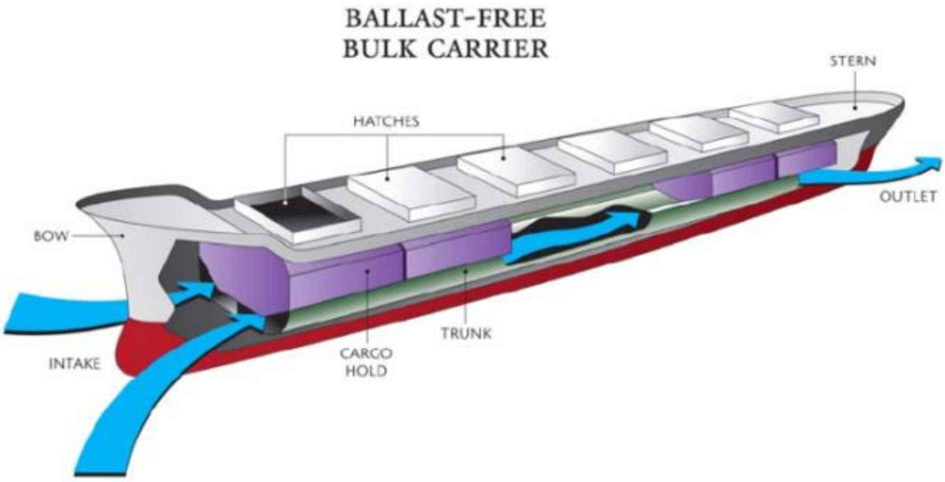


Figure 38. variable buoyancy system proposed by the University of Michigan. - Source: https://safety4sea.com/wp-content/uploads/2018/09/ballast-free-concept-e1536847793974.png

- V-hull design for ballast-free ships:

  This alternative method does not eliminate completely the ballast water system unlike the other methods we have explained. In this case, the idea is to design a V-hull that can have a safe and effective stability in different conditions (full of cargo, in ballast…) without the need of using ballast water. However, the idea is to have a few tanks that can temporary store ballast water in case of emergency (i.e. bad weather) so as to increase the draft and assure the safety of the vessel (59).

  The V-hull design is now being applied to a LNG Carrier that it is being built and it can become the first merchant ship to be considered a ballast-free ship. The LNG Carrier of 7,500 cubic metres is being built for a German company called Bernhard Schulte. It commenced the construction of the vessel in November 2017. The company in charge of building the vessel is the South Korean shipyard Hyundai Mipo Dockyard (61).

  Main advantage for this method, apart from the costs saving associated to the BWM Systems, is that the vessel can have a longer service life as there will be no corrosion inside the vessel as there will be no sediments in the ballast tanks. In addition, it can represent a benefit for the crew as the task of assuring a correct maintenance or execution of the BWM System will no longer exist.

Main disadvantage for the V-hull design is that it is still a project and it needs some years to show the real results.

In Table 7, there is a brief comparison among the three different alternative methods for improving the stability of the vessels without the need of the use of ballast water that we have seen during this chapter:

MAIN FEATURES	25 TONNE CONTAINERS	VARIABLE BUOYANCY SYSTEM	V-HULL DESIGN
STUDY MADE BY	Daewoo Shipbuilding & Marine Engineering.	University of Michigan.	Hyundai Mipo Dockyard
IDEA	Use the weight of 25 tonne containers.	Use of seawater to modify the buoyancy.	Modify the hull design.
MAIN ADVANTAGE	- No use of BW. - No wear of the tanks.	- No use of BW. - Use of seawater without needing storage.	- No use of BW. - Longer service life. - No corrosion.
MAIN DISADVANTAGE	- Need of carry 25mt containers on board or to have them in ports of call.	- Higher operational (wear of the hull) and building cost.	- Not yet proved its results.
REGULATION	No regulation.	No regulation.	No regulation.

Table 7. Comparison summary of the different ballast-free methods analysed. - Source: author

In conclusion, we have seen 3 different alternative methods to the conventional use of Ballast Water Management Systems for improving the stability of the vessel. Nowadays, the only concern for the maritime sector is to meet the standards that IMO stablished on the BW Convention.

Main reason for not existing more investment for the study and construction of free ballast ships is that currently, is that it does not exist an important regulatory pressure that can push shipowners/operator to invest in alternative methods. The only way to improve the efficiency and the eco-friendliness on the future is to reduce the use of BWM Systems and to implement alternative methods that can perform the same purpose without putting at risk the environment or the human health.

Chapter 7. Conclusion

For having a proper overview of the conclusions that we will expound, the different chapters will be analysed separately for extracting main ideas that we need to take into account (not considering the chapter 1, Introduction). Subsequently, final conclusions will be extracted to understand key points of the ballast water problem and to consider which system can be not only the cleanest but also the most efficient.

7.1 Ballast Water Management Convention

The International Convention for the Control and Management of Ships' Ballast Water and Sediments, which entered into force last year 2017, has become an essential regulation for the control of the ballasting and de-ballasting operations by worldwide vessels. Before the IMO entered into action, many cases of invasive species have been recorded, being mainly produced from the ballast water used for ships stability.

On the one hand, the Convention, and its compulsory standards D-1 & D-2, has played an essential role for avoiding the spread of invasive species and for reducing the impact of vessels on local environments.

On the other hand, despite BWM Convention can achieve a big reduction of the impact thanks to the obligation of a proper treatment of the BW, it is still necessary a bigger control from different authorities (Port State Control, for example) to avoid malpractice de-ballasting. Therefore, the control of BW discharge can still be more controlled to avoid ecological problems. In addition, we must not forget that world fleet is continuously growing, increasing the risk caused by the BW.

7.2 Treatment technologies

The treatment technology is one of the most important actors for reducing the impact of BW from ships. BWM Systems have the role of treating the ballast water correctly in order to eliminate the organisms from the seawater loaded on ballast tanks.

Many treatment systems have been studied and manufactured by the shipping industry, being almost impossible to recommend none of them above the others. Anyway, it is important to remark that the use of systems which are not based on chemical products can represent the cleanest way of treating the BW, assuring not polluting the environment when de-ballasting.

Finally, we would like to remind that for a proper control of the levels of organisms it is needed the use of 2 or more systems that, combined, can perform correctly the task of reducing the impact of BW.

7.3 Process of study, installation and control of BW Management System

Despite this chapter is a descriptive part of the study and there is no information to be analysed, it can be concluded that BWM Convention represented a huge economic impact for the shipowners and the charterers as they needed to adapt their vessels to the new standards. Therefore, newbuild vessels had an advantage over existing vessels as the design is already made from the beginning, taking into consideration the system that the vessel will require.

7.4 Comparative analysis of different BWM Systems

Different BWM Systems have been studied during the work in order to observe strengths and weaknesses: Wärtsilä Aquarius UV, BalClor BWM System, JFE BallastAce and ClearBallast. All of them are using different methods for treating for ballast water and we can conclude that:

a) Wärtsilä Aquarius UV can represent a good option for those vessels that do not need big volumes of ballast water and do not sail in turbid waters (as the efficiency is clearly reduced). Furthermore, it is an eco-friendly method that does not use any type of chemical that can result harmful for the environment.
b) BalCor BWM System is the system studied offering biggest capacity of BW, representing a perfect option for vessels that have big ballast tanks. As we have seen, currently it is a system that is mainly used by bulk carriers and tankers, which need big volumes of BW to compensate the forces depending on the circumstances (full load, half load or in ballast conditions).
c) JFE BallastAce is currently mainly used by bulk carriers that can manage their stability with a capacity of ballast water of 3,000m^3/h maximum. Main disadvantage of this system is that it requires to train properly the crew members and to have regular supply of the chemical used. For this reason, it is a system that can represent a limitation for many vessels that cannot afford the storage of much chemicals on board (due to space) or that does not call ports regularly.
d) ClearBallast cannot offer a big capacity (2,400m^3/h maximum) and main disadvantage is that it requires a big space on board for its installation. The big space is needed as it is the only system studied that requires the combination of 3 different methods to treat the BW (Coagulation, Magnetic treatment and Filtration).

Finally, it is important to remark that there is not one BWM System recommended above the others. Every method and every system has different features. Therefore, the suitability to a particular vessel will depend on its characteristics and needs (dimensions, BW needed, type of cargo, usual sailing route…).

7.5 How to reduce Ballast Water impact

Firstly, there are still many different ways to improve the control over the treatment and discharge of ballast waters from ships. In this way, there are many proposals that need to be considered in order to reduce the impact of the BW in the near future. Some of most important proposals are the installation of ballast tanks sediments reception and disposal facilities in different ports or the improvement of Port State Control for assuring a correct use of the BWM Systems. These proposals can clearly contribute to reduce the impact of ships to the environment.

Secondly, in the near future it will be required to reduce the use of BWM Systems and to increase the use of alternative methods that can substitute the role of the BW. For this reason, it is essential to launch new designs like the V-hull that can clearly contribute to achieve ballast-free vessels that can sail and perform operations without the use of ballast water. These alternative designs clearly need to ensure a good level of efficiency and security for substituting completely the role of BWM Systems. In addition, this type of design can achieve a long service life due to the reduction of corrosion caused by seawater.

Thirdly, there is still a big margin for achieving a complete reduction of the BW. Main problem is that for implementing the measures we have researched or for studying new methods to substitute the BWM Systems, it is required in many cases a big investment. That is the reason why not only shipowners but also Governments/International organizations are not pushing for a better solution for the moment.

7.6 Final conclusions

During the whole investigation, we have been trying to understand the importance of ballast water on maritime industry and to make a special research on different BWM Systems. Thanks to the comparison among the different systems and the detection of weaknesses/strengths of the ballast water, we can conclude that:

a) Despite ballast water can clearly contribute to vessel's stability, reduction of stress of the hull or increase the manoeuvrability during navigation; it can have a big negative impact on the environment (transport of invasive species), the economy (food industry or tourism) and human health (polluted animals). In general, we can conclude that BW represents a benefit for the vessel but a harm for her surroundings. In addition, we need to remark that worldwide fleet is continuously growing, increasing the impact of the ballast water.
b) Ballast water has currently an indispensable role on the stability of ships. For the moment, there are no alternative methods for the stability and for this reason it is essential to have a correct regulation that can control the correct ballasting and de-ballasting operation.
c) Standard D-2 has become probably most important regulation for the reduction of ballast water impact from ships. Thanks to the standard, it can be controlled the concentration of organisms and it is easier for vessels and authorities to ensure that the regulation is being followed.
d) Despite the different regulations of The International Convention for the Control and Management of Ships' Ballast Water and Sediments, ballast water is still a threat for the environment, the human health and the economy. For this reason, it is essential continue controlling and regulating the de-ballasting of the ships to minimize the risk.
e) There are many methods for the treatment of ballast water that can carry out the process correctly with different characteristics. In this way, we can conclude that there is not a specific

method better than the other. The only condition for assuring a correct treatment of the seawater is to use 2 or more methods combined in the same system. Finally, it is preferable the use of methods that can work without the use of chemicals as the risk of pollution will be clearly reduced.

f) About BWM Systems, we have seen that every system has different characteristics and no one is better over the others. Generally, the BWM System choice will depend completely on vessel needs, route, characteristics, type of vessel, etc. When deciding which one suits best for a specific vessel, a proper study needs to be carried out to ensure that the needs of the vessel will be fulfilled and that all aspects for her design are taken into account.

g) Alternative designs to achieve ballast-free vessels need to play a special role in the near future. For achieving this type of vessel, it will be required a big investment and effort not only from the maritime companies but also the Governments or International organizations.

h) The use of alternative designs can represent a clear cost saving in the long term (maintenance, valves, pumps, systems...) while using a completely eco-friendly stability method, without the use of ballast water. Furthermore, there will be no need of complying with regulations regarding ballast water, having less control and bureaucratic processes.

I would like to conclude by saying that despite the Convention has been an essential step for the control and treatment of ballast water, now it is needed the action of the international organizations to reduce the use of ballast water. Best way for pushing different actors to invest and study new methods for the stability of the vessels, is to toughen the regulation and the control of ballast water usage. It will be the only way to push different actors to take part of the problem and to reduce the use of ballast water worldwide, one of most important impacts to the environment from ships.

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